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AWARD NUMBER: DAMD17-00-C-0031

TITLE: Mathematical Modeling in Support of Military Operational Medicine

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REPORT DATE: July 2006

TYPE OF REPORT: Final

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
01-07-2006	Final	7 Aug 2000 – 6 Jun 2006

4. TITLE AND SUBTITLE

Mathematical Modeling in Support of Military Operational Medicine

5a. CONTRACT NUMBER
DAMD17-00-C-0031

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

L-3 Communications/Titan Corporation
San Diego, California 92121

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The research conducted under this contract has provided critical hardware, software, and knowledge products to assist the MOMRP effort. This report summarizes those products in the following areas: Blast Injury Research, Behind Armor Blunt Trauma Research, Inhalation Toxicology Research, Head and Neck Injury Research, Distributed Thoracic Trauma Research, Biomechanics Research, and Data Preservation. Much of the work has appeared in peer-reviewed journals. Key software products are distributed through the MOMRP web site. Critical hardware is used throughout the military for assessment. In our own small way, L-3/Jaycor has helped the Military Operational Medicine Research Program meet its objective that "MOMRP research touches every soldier, every day."

15. SUBJECT TERMS
blast overpressure, injury, modeling, blunt trauma

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			USAMRMC
U	U	U	UU	76	**19b. TELEPHONE NUMBER** *(include area code)*

communications

Applied Technologies

Modeling for Military Operational Medicine Scientific and Technical Objectives

Final Report J3150.01-06-306
Contract No. DAMD17-00-C-0031

Prepared for:
Commander
US Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5014

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July 2006

Contents

Page

1. Introduction

The Military Operational Medicine Research Program (MOMRP) of the US Army Medical Research and Material Command (USAMRMC) faces ever increasing pressure to answer more mission questions with less resources and time. The Catch-22 aspect is that problems cannot be satisfactorily solved at the moment they arise unless the supporting research basis has already been laid. Consequently, it is imperative to be proactive: anticipate need and put in place the broadest infrastructure of applied research that can be practically accomplished.

Blast overpressure, NLW, and vehicular crash data show that internal organ injury is wide spread and has significant performance and treatment consequences. Criteria to estimate the hazard to some organs exist for specific contexts, such as vehicular accidents, but they do not readily transfer to military applications. The understanding of critical internal organ injuries must be unified and expressed in a biomechanically correct form so any future hazard circumstance can be readily addressed (see tables on next page).

At the other end of the trauma spectrum is local contusion and penetration. The need to understand these threats comes not only from the historical concern for penetrating wound, but is being driven by the emergence of military use of kinetic energy nonlethal weapons and concerns for selecting materiel based on behind armor trauma. Current criteria do not address the effects of clothing or body fat and are under pressure for major revision or elimination. For the MOMRP to be able to assess these threats and to advise on protective measures, the criteria will have to be placed on a biomechanically and physiologically sound basis.

Soldier performance and nutritional needs under external stress, whether it be from trauma, hazardous materials, or environmental conditions, is a principal focus of the MOMRP. While there are many complex physiological and psychological factors at work, one well-documented component is the biophysical response. Combining the biomechanical models that relate local external conditions and local organ response with mathematical descriptions of the systemic response of the body provides a unified and generalized description needed to extend previous results and anticipate new needs.

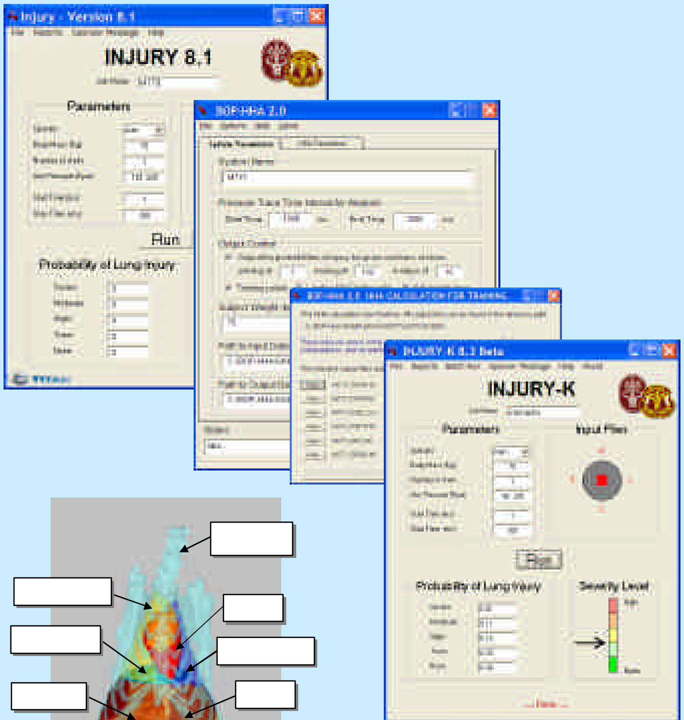
Threats to the soldier are growing in nontraditional areas, such as acoustic, electromagnetic, ionizing radiation, chemical, and biological weapons. These threats have both a physical component (coupling of the external threat to the organs of the body) and a systemic effect (disruption of the normal protection and response functions). Although many of the physical interactions are known, they have never been combined with physiological response to produce a quantitative and predictive methodology. The infrastructure needed to allow the MOMRP to respond effectively should include these effects.

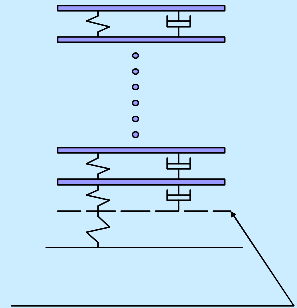
The research conducted under this contract has provided critical hardware, software, and knowledge products to assist the MOMRP effort. This report summarizes those products in the following areas:

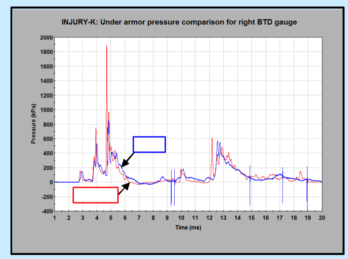
- Blast Injury Research
- Behind Armor Blunt Trauma Research
- Inhalation Toxicology Research
- Head and Neck Injury Research
- Distributed Thoracic Trauma Research
- Biomechanics Research
- Data Preservation

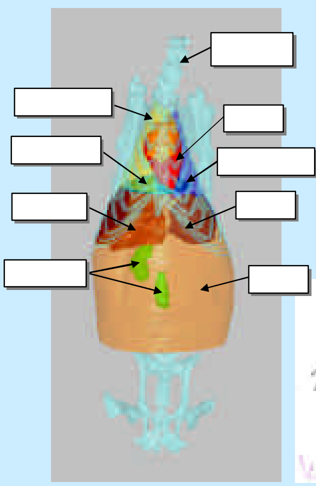
Much of the work has appeared in peer-reviewed journals. Key software products are distributed through the MOMRP web site. Critical hardware is used throughout the military for assessment. In our own small way, L-3/Jaycor has helped the Military Operational Medicine Research Program meet its objective that “MOMRP research touches every soldier, every day.”

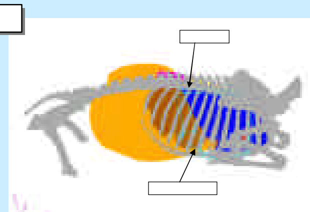
2. Blast Injury Research

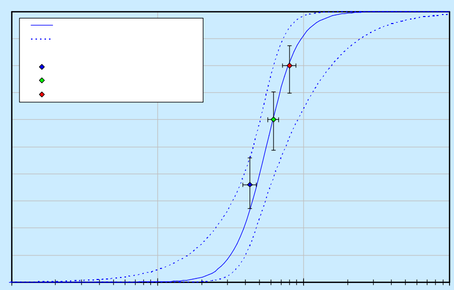


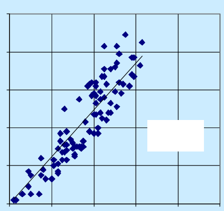


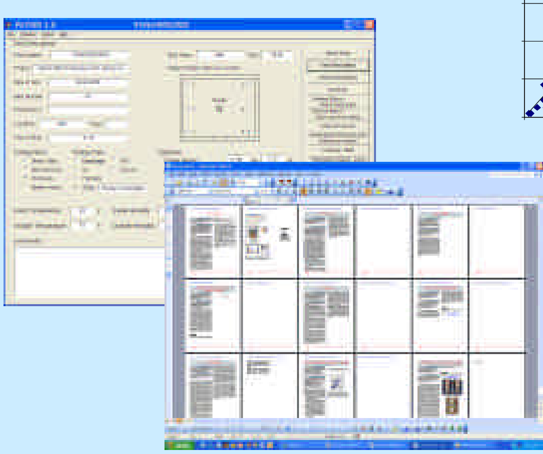












INJURY CODE

Significance

The INJURY computer code provides a valuable tool for use in assessment of the risk of injury from occupational exposure to blast overpressure.

Product

--INURY 8.2 Computer Code Release, January, 2006.

--Lung Injury Model Description, Masiello, P. J., Report J3150.104-06-300, Feb. 2006.

--INJURY 8.1 Computer Code Release, September, 2004.

--Lung Injury Criteria for Air Blast Trauma, Masiello, P. J. and Stuhmiller, J. H., Report J2997.24-01-158R1, December 2003.

The INJURY computer code provides the U.S. Army Medical Research and Materiel Command (USAMRMC) with a standardized tool for the assessment of injurious effects of air blast. The model in the code addresses specifically the contusive lung injury arising from repeated exposure to air blast, and includes a computational model for predicting the response of the chest wall and the accompanying irreversible normalized work done on the lung. Enhancements to the numerical scheme used in earlier versions of INJURY software, and to the physical model used to predict lung response, were important objectives of the present phase of code development.

The correlations for lung injury employed by INJURY make use of a multitude of BOP test programs spanning over two decades, and entailing over 1100 animal subjects. Correlations for four levels of injury (trace, slight, moderate and severe) allow prediction of the likelihood of different spatial extents of contusive lung injury, based on the relative area of lung surface exhibiting hemorrhage in pathology data during BOP testing with animal surrogates.

The normalized work done on the lung and the number of repeated exposures to blast are the risk factors for lung injury used by INJURY in its assessment of the probability of injury. The input data to the code consist of subject mass, species (presently, man or sheep), ambient pressure, number of exposures, and pressure time history data at four locations on a Blast Test Device (BTD) instrument specially designed for BOP testing.

Some of the more recent improvements to the INJURY computer code and model include:

- An improved numerical method used in lung response calculations. The solution to the time dependent chest wall response is now obtained with the use of a fifth order Runge-Kutta technique, resulting in a significant improvement in accuracy and computation time.
- An *effective* normalized work is now employed, which accounts for directional air blast effects (e.g., subject orientation) and nonlinearity of work done on the lung relative to injured lung area.
- New logistic regressions for probability of injury have been formulated, based on the most recent quality assurance by L-3/Jaycor of the MRMC animal test database.
- The new regressions are based on a *nonlinearized* form of normalized work. This leads to a greater degree of accuracy, especially for the most energetic air blasts.
- The lung response model has been assembled into a distinct module that can now be used by other applications.

BOP-HHA 2.0

Significance

Provides a valuable health hazard assessment tool for evaluating the likelihood of nonauditory injury resulting from repeated occupational exposure to air blast effects during weapon systems training.

Product

--BOP-HHA User's Guide, Masiello, P.J., Report J3150.104-06-304,June 2006.

--BOP-HHA 2.0 Computer Code for Nonauditory Health Hazard Assessment, Release date March 6, 2006.

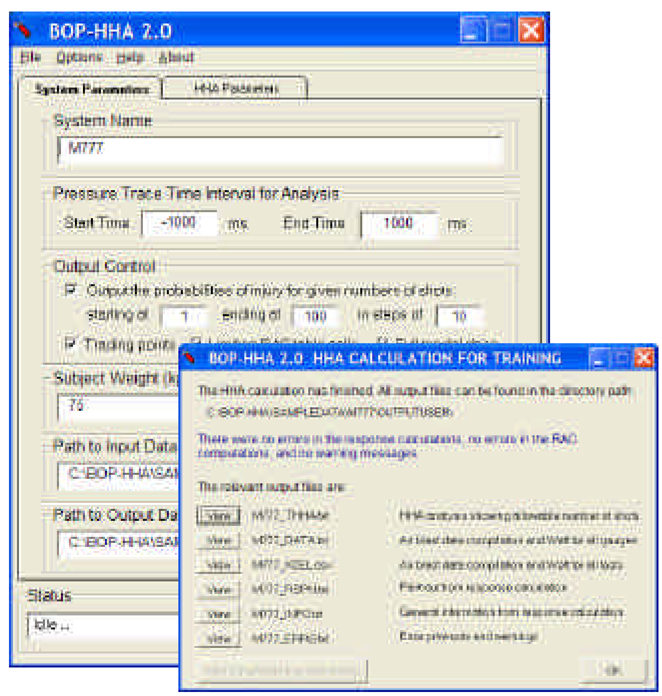
--Lung Injury Model Description, Masiello, P. J., Report J3150.104-06-300, Feb. 2006.

--BOP-HHA 1.0 Graphical User Interface and Output Data Description, D. E. Goddard and P.J. Masiello, presented to CHPPM, June 13, 2005.

--BOP-HHA 1.0 Computer Code for Nonauditory Health Hazard Assessment, Release date October 6, 2003.

The BOP-HHA (Blast Overpressure - Health Hazard Assessment) family of software has as its origin the INJURY computer code, also developed by Jaycor/Titan. User feedback from CHPPM pointed to the need for additional features and code enhancements relative to the initial release, denoted as INJURY 7.1. The need existed for an effective computational tool that could output Risk Assessment Codes (RAC) and address combinations of different exposures (e.g., charge weights, crew positions). Simplification of user input was an essential goal, since key input parameters (e.g., number of shots in system lifetime) in the initial version of the software were sometimes difficult to determine. Enhancements to the numerical scheme and to the physical model used to predict lung response were also important objectives in this work. Continued development, testing, and response to user feedback led to the following code improvements:

- A simplified user interface, eliminating the need to input the desired number of shots per day and total number of exposures in the system lifetime.
- Improved, simplified, and expanded output in tabular form, displaying the maximum allowable number of shots per day for each of five possible values of RAC.
- Calculation and display of "trading points" which allow assessment of the likelihood of injury due to combined effects of exposure to different charges in a single day. Also allows assessment of a single crew member moving to different positions, and possibly exposed to different charges at each position.
- Option to output probabilities of injury
- An improved numerical method used in lung response calculations utilizes the fifth order Runge-Kutta technique, resulting in improved accuracy.
- An *effective* normalized work (a key risk factor for injury) now accounts for directional air blast effects (e.g., subject orientation).
- New logistic regressions for probability of injury have been formulated, based on extensive quality assurance of the MRMC animal test database.
- The new logistic regressions are now based on a nonlinearized form of normalized work, leading to a greater degree of accuracy, especially for the most energetic air blasts.



VIRTUAL SHEEP

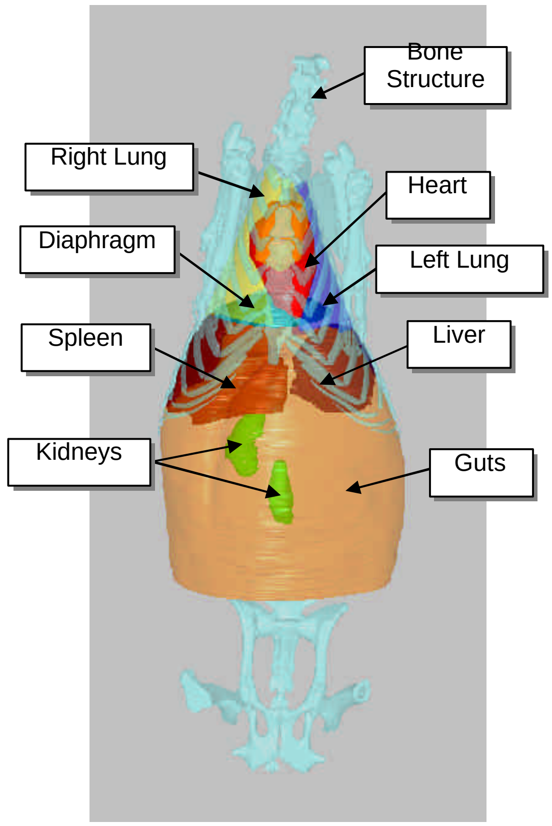
Significance

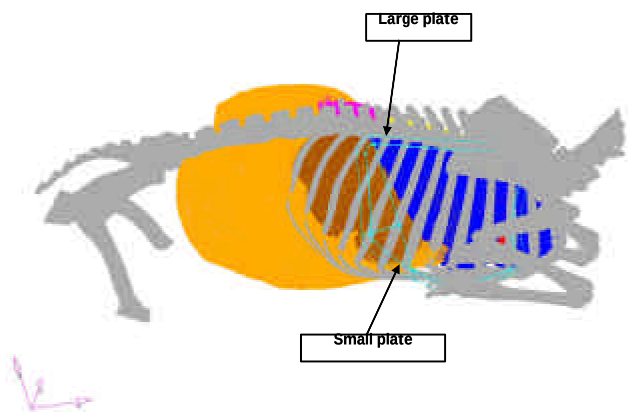
A virtual three-dimensional digital image of a sheep subject has been constructed using computed tomography (CT) data. The virtual sheep is used for supporting the Army ATO in sizing armor plates for blast test and interpreting the implication of the pathology data for humans, and it will be used for finite element model development.

Product

–Blast Load Phenomena and Instrumentation Development, Vol. 1 for Individual Protection Against Novel Blast Threats – ATO, Chan, P. C. et al., Report J3150.101-05-266, Nov. 2005.

A virtual sheep has been constructed using computed tomography (CT) image data. The CT data were scanned using a frozen sheep carcass. Using the CT data, the geometry of the sheep and all the internal organs were constructed. The virtual sheep is needed for sizing the armor plates over the thorax for blast field test. Furthermore, since the locations of the internal organs are different between sheep and humans, the virtual sheep can be used to support the interpretation of the implication of blast load path and injury patterns obtained from sheep tests for humans, especially when armor plates are placed on the thorax. The virtual sheep will also be used for construction of finite element models for simulation analyses.





Model of Blast Effects on Kevlar Jacket

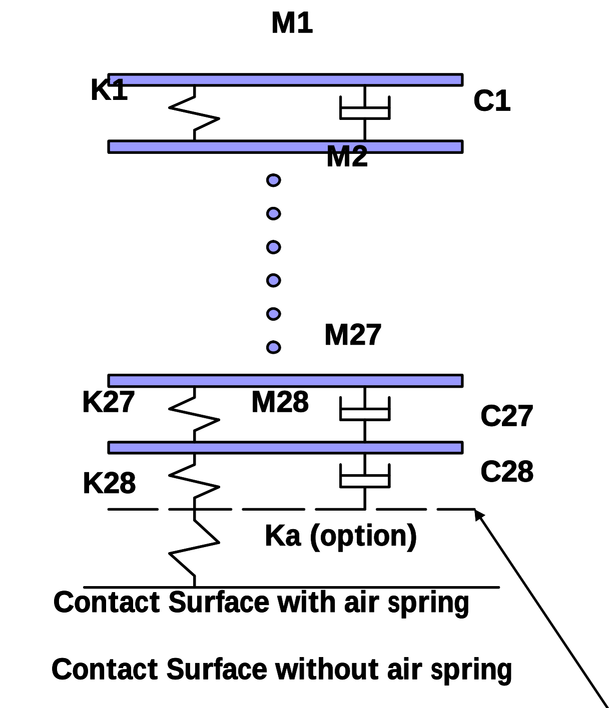
Significance

A 28-layer Kevlar model has been developed and validated against shock tube data. The model simulates the material used for body armor and has been coupled to INJURY for normalized work calculation with favorable comparison with field data.

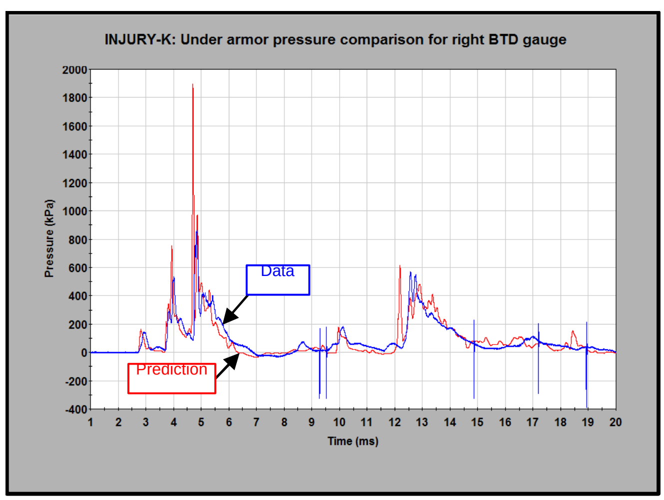
Product

–Blast Load Phenomena and Instrumentation Development, Vol. 1 for Individual Protection Against Novel Blast Threats – ATO, Chan, et al., Report J3150.101-05-266, Nov. 2005.

A one-dimensional 28-layer Kevlar model simulating the body armor jacket material has been developed and validated using shock tube and field test data. The 28 Kevlar layers are modeled as 28 masses connected with parallel springs and dampers. The spring and damper materials are nonlinear and derived from material test data. An air spring option is available for simulating the gas dynamics effects at the bottom layer contacting the target surface. A hard plate can be added to the top of the Kevlar layers to simulate the ballistic plate. To simulate the body armor, the equivalent mass areal densities of the plate and Kevlar materials are used. The model has been coupled to INJURY 8.1 (Stuhmiller, 1996) for calculation of normalized work with armor effects with limited, yet favorable data comparison. The model is being used to support the Army ATO for Individual Protection against Novel Blast Threats.



28-Layer model schematics



Validation Results

Cited References:

Stuhmiller, J. H. et al. (1996) "A Model of Blast Overpressure Injury to the Lung," *J. Biomechanics*, Vol. 29, No. 2, pp. 227-234.

L3 communications

INJURY-K

Significance

The INJURY-K code provides a means of assessment of the extent of air blast injury to soldiers protected by multilayer body armor and has immediate application to the design and testing of individual protection systems such as the body armor 28 layer Kevlar vest.

Product

--INJURY-K Computer Code, Version 8.1 Beta, Jan. 10, 2006, Paul J. Masiello, L-3 Communications Corporation.

--28 DOF Model of Body Armor, Xinglai Dang, L-3 Communications Corporation, presented to Natick Soldier Center, May 27, 2005.

The INJURY-K computer code provides MRMC with an important tool for the assessment of potential air blast injury to soldiers protected by multilayer body armor. The user interface, probabilistic injury model, and chest response model in the code all originated with the INJURY computer code, also developed by L-3/Jaycor.

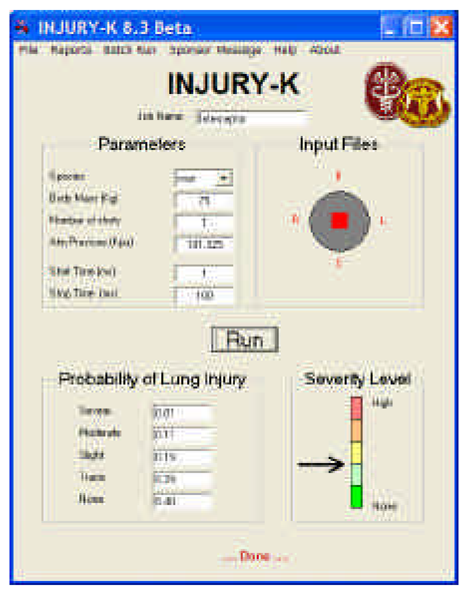
The 28 degree of freedom Kevlar vest model was developed by L-3/Jaycor under the *Individual Protection Against Novel Blast Threats* ATO supported by the Natick Soldier Center (NSC), Natick, Massachusetts. Similar to the chest wall response model in INJURY, this model also employs spring-mass-damper components for simplicity and computational efficiency. The 28 layer vest model has been calibrated and verified by in-house shock tube tests conducted at L-3/Jaycor.

The complete response model in INJURY-K addresses the blast overpressure acting on each of four sides of a human thorax. The model automatically (and optionally) includes a hard plate in addition to the Kevlar on the anterior and posterior surfaces of the thorax, and models only the 28 Kevlar layers on the left and right sides, where a plate is not present in the Kevlar design. The blast overpressures that are input to the model are measured by a Blast Test Device (BTD) not fitted with armor, but INJURY-K also can also accept measured under armor data, in which case the vest and plate are not modeled by the code.

The equations describing the motion of the plate and each of the 28 Kevlar layers are solved by means of an efficient and accurate Runge-Kutta computational technique. The Kevlar layer closest to the thorax is coupled to the chest wall motion. Local and global damping of each Kevlar layer is included in the model. A stress-strain relationship valid for compression of Kevlar fabric is employed for calculation of internal forces between layers. The stress in tension is assumed to be zero. Hence, the layers are free to separate, and can rebound from the chest wall.

Output data from INJURY-K include the irreversible normalized work done on the lung as well as probabilities of four levels of lung injury. In addition, the time histories of under armor pressure and of chest wall motion can be saved in easily read disc files.

INJURY-K code predictions for under armor pressure have shown excellent agreement with pressure time history data measured under the Kevlar vest fitted to Blast Test Devices (BTD's) during BOP testing in an enclosed bunker, over a practical range of charge weights.



BLAST LETHALITY CORRELATION

Significance

A blast lethality correlation with normalized work has been developed using the historical MRMC BOP data and INJURY 8.1. The correlation agrees with the latest data collected from novel blasts.

Product

--Blast Load Phenomena and Instrumentation Development. Vol. 1 for Individual Protection Against Novel Blast Threats – ATO, Chan, P.C., et al., Report J3150.101-05-266, Nov. 2005.

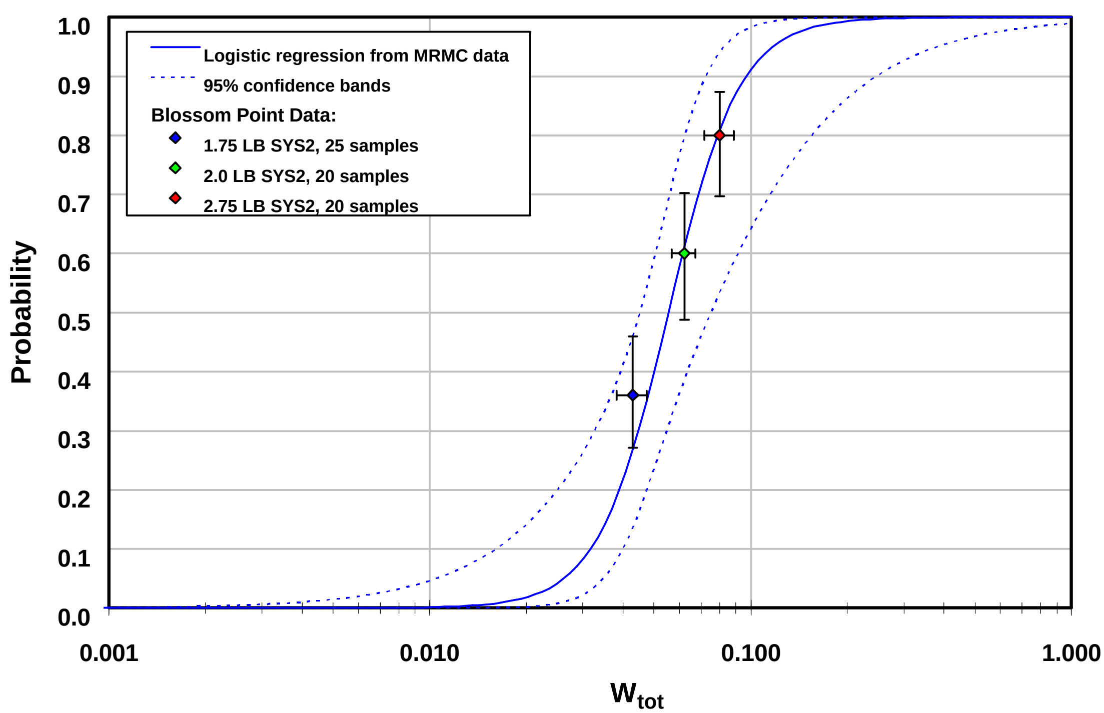
A blast lethality correlation with normalized work (Stuhmiller 1996) has been developed using a subset of the MRMC BOP complex wave data with fairly tight 95% confidence band. Normalized work is calculated using INJURY 8.1. The correlation agrees with the latest data collected for novel/ thermobaric blasts. The result shows that normalized work is a biomechanical correlate to blast lethality. The correlation is being used to support the Army ATO for Individual Protection against Novel Blast Threats. The correlation is shown in the figure below with the latest ATO data indicated. It is recognized that the extent of lethality data at present is still limited. As more data are being collected, the lethality correlation may be refined.

Cited References:

Stuhmiller, J. H. et al. (1996) "A Model of Blast Overpressure Injury to the Lung," *J. Biomechanics*, Vol. 29, No. 2, pp. 227-234.

INJURY 8.1 at http://www.momrp.org/index.htm

Lethality Correlation Deduced from MRMC Data



communications

PATHOS 3.0

Significance ⏩

The PATHOS 3.0 computer code provides for a means of entering, editing, storing, and maintaining pathology data from BOP tests employing live targets, and also serves to establish a standard for pathology scoring.

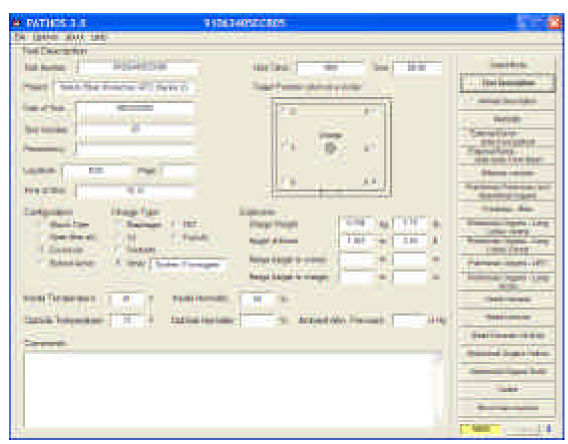
Product ⏩

--PATHOS 3.0 Computer Code, release date September, 2005. Installation executable provided to Natick Soldier Center, Natick, MA.

In the early 1990's, Jaycor developed the PATHOS code, an interactive DOS-based menu oriented computer program that allowed efficient storage and manipulation of large amounts of pathology data. The early PATHOS code proved particularly useful in a time period when extensive pathology data were being generated in a series of complex wave blast overpressure (BOP) test studies conducted at the Lovelace Institute in Albuquerque, NM. In addition, there was an abundance of live target test data from earlier BOP studies, dating back to the early 1980's, mainly preserved in hard copy format. The continuing need for an interactive computer program for entering pathology data brought about the release in 1995 of PATHOS 2, a user friendly Windows-based program employing the Microsoft Access database format. PATHOS 2 and its predecessor made use of pathology sheets that were devised by the veterinary pathologists performing the necropsies, as well as other research staff participating in the various animal test programs. The type and extent of pathology data handled by PATHOS was in keeping with data recorded during those programs. Subsequent to 1997, the PATHOS 2 code was essentially dormant, since BOP testing with live targets had already reached its culmination.

In 2005, a test program, conducted by the Natick Soldier Center (NSC) employing live targets, *Individual Protection Against Novel Blast Threats*, called for renewed use of a program similar to PATHOS2. The requirements of this study dictated that a more extensive set of pathology data be maintained for each test subject. A new set of pathology scoring sheets was agreed upon, suitable for meeting the specific goals of the NSC study. Live target testing began in 2005 and was carried out at the ARL Blossom Point facility in Welcome, MD. This test study will provide an additional wealth of pathology data, with approximately 800 live targets in the proposed test plan. In order to meet the needs of the Blossom Point test study, the PATHOS 3 code was developed by Jaycor/Titan (now a part of L-3 Communications, Incorporated) during the summer of 2005 and released to NSC in September 2005.

The PATHOS 3 code features a specially designed MS Access database having over 850 fields and over a dozen tables. Design of this database was a significant part of the task of PATHOS3 code development. Part of this effort involved choosing a design such that the new database can merge easily with the existing MRMC database of historical test data, maintained by Jaycor/Titan. Pathology data for all organs of interest are accommodated by PATHOS3, in addition to data for morbidity, time dependent administration of anesthesia, and blood gas analysis.



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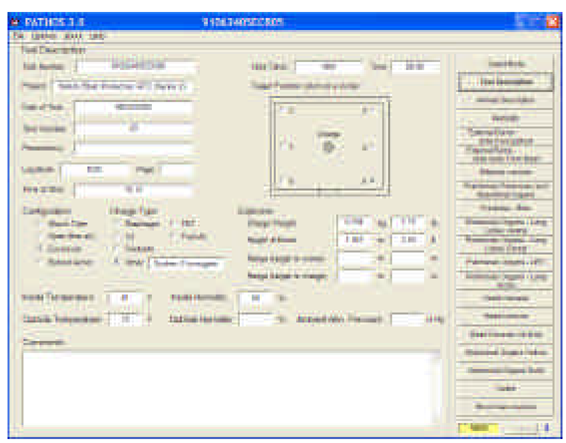


COMPUTER ASSISTED PATHOLOGY SCORING

Significance

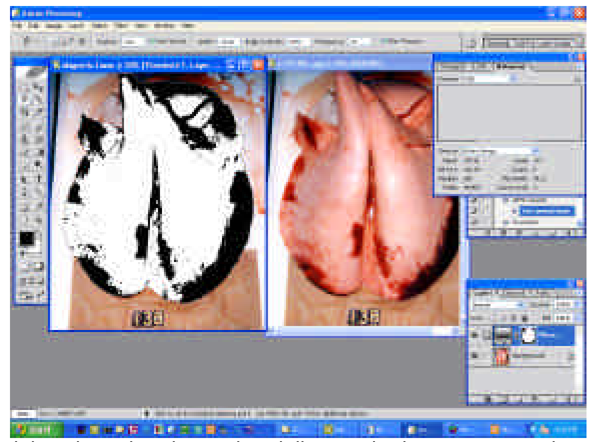
Image processing of pathology photographs assisted by human judgment gives more accurate quantitative results in scoring lung injury than the on-site prospector's estimates; and in addition provides archival documentation for possible future evaluation.

Product

--Computer Assisted Pathology Scoring, Michael Vander Vorst, Brenda Tracy, Philemon Chan, Presentation to Natick Soldier Center, March 2006.

--Specifications for Pathology Photography of Blossom Point Tests, Michael Vander Vorst, Technical Note J3150.82-05-301, Nov. 2004.

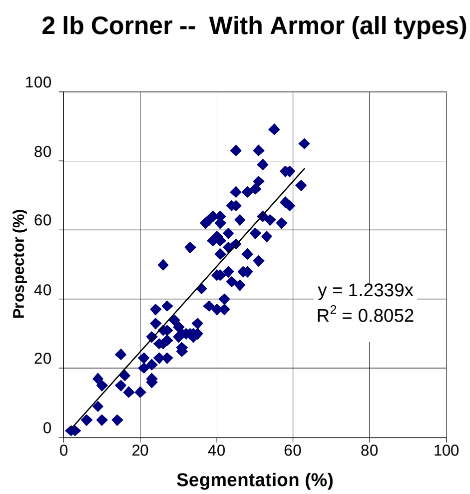
--User Guide for Scanning and Archiving Pathology Records, Paul Masiello, Technical Note, Dec. 2004.



Adobe Photoshop is used to delineate the lung, segment the injured area and then calculate the percentage of injury

Methods and protocols were developed to photograph, document, analyze and quantify the injury pathology from the Blossom Point Blast Tests as part of the Natick Soldier Center Blast Protection Program. A summary of the steps in the process is:

1. A lighting system was set up to obtain consistent and reproducible color in the digital photographs, and which minimized shadows and specular reflections and glare.
2. A scanning system and procedures were put in place on-site to immediately acquire pathology reports and log books in digital format.
3. A database of all results using redundant disk array and independent daily backups was established to organize all of the test data.
4. Procedures and macros to color balance the digital photographs, delineate the specimen from the background and segment the injury were developed using Adobe Photoshop.
5. The results of the computer assisted segmentation of the digital images were compared with the prospector's injury estimates from the pathology reports.



On average, the prospector's scores and the result of the computer assisted pathology scoring are in good agreement. However, inspection of individual results show that the computer assisted scoring is more accurate and self-consistent. In any case, human judgment is still required in the segmentation process.

FORCE-BASED BLAST TEST DEVICE (FBTD)

Significance

The Force-based Blast Test Device (FBTD) has been developed for collecting blast load data under clothing/armor coverings for inputs to INJURY for prediction of blast lung injury and lethality.

Product

–Blast Load Phenomena and Instrumentation Development, Vol. 1 for Individual Protection Against Novel Blast Threats – ATO, Chan, et al., Report J3150.101-05-266, Nov. 2005.

A new Force-based Blast Test Device (FBTD) has been developed for measuring blast load under clothing/armor coverings. The FBTD has the same dimension as the original BTD, which is 30” tall and 12” in diameter. Using modular design, the FBTD is composed of three equal sections. The top and bottom sections are support sections that can be connected to mounting structures that are usually customized for each test set up. The middle is the sensor section, which is further divided into four equal quadrants for the front, right, back and left sides, respectively. Each quadrant contains an independent sensor panel that can be opened for sensor mounting, cable connections and maintenance without the need to dismount the FBTD. Each sensor panel is designed to have a 3x3 matrix of pressure sensors for measure load distribution. A maximum of 36 pressure sensors can be used for each FBTD. PCB 102A06 flush tip pressure sensors are required. The FBTD has been field tested and is being used to support the Army ATO for Individual Protection against Novel Blast Threats. The algorithm for using the FBTD data as inputs to INJURY 8.1 for calculating normalized work (Stuhmiller, 1996) will be available in 2006. The FBTD can be used like the BTD without clothing/armor covering if only one sensor is used at the center for each sensor panel for collecting data as inputs to INJURY 8.1 for prediction of blast lung injury for bare conditions.

Cited References:

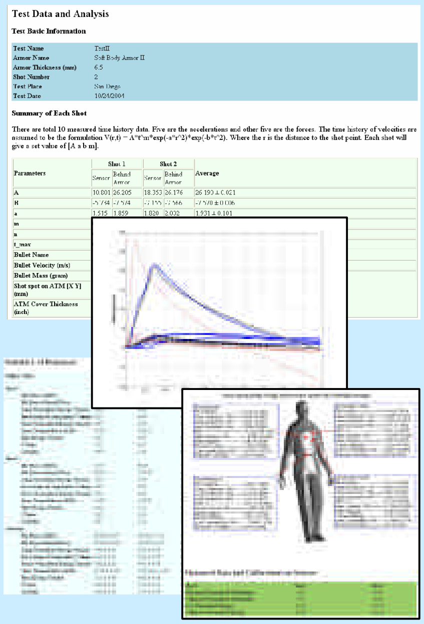
Stuhmiller, J. H. et al. (1996) “A Model of Blast Overpressure Injury to the Lung,” *J. Biomechanics*, Vol. 29, No. 2, pp. 227-234.

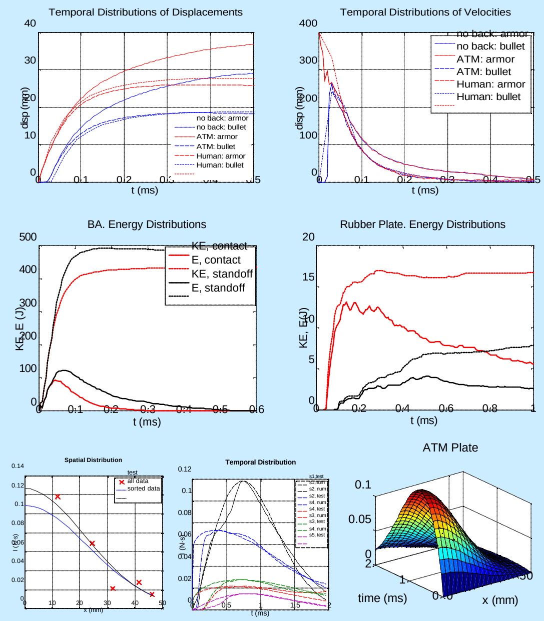
INJURY 8.1 at http://www.momrp.org/index.htm

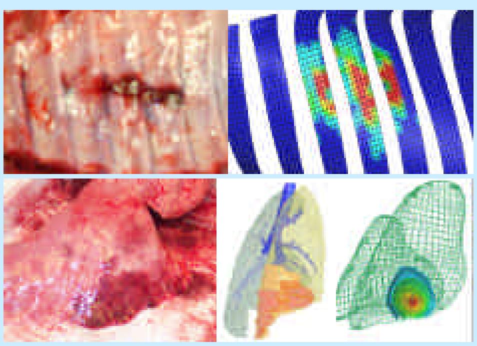
FBTD (Right photo with front sensor panel off)

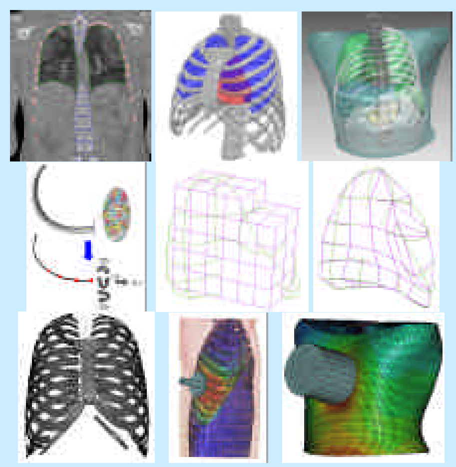
FBTD with surrogate armor in field test

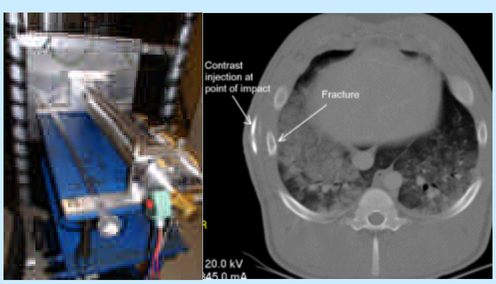
3. Behind Armor Blunt Trauma Research

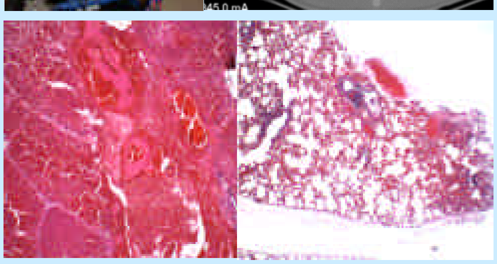


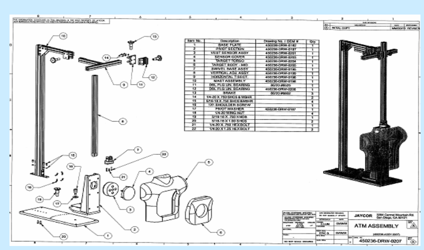


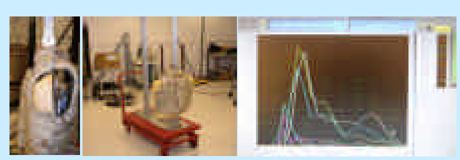












BEHIND ARMOR BLUNT TRAUMA ASSESSMENT PROGRAM (BABTAP)

Significance

- Web-based user friendly interface
- Three-tie layered architecture: Client (user application) domain, integrated models domain and data management
- Report generation by select-click procedure
- Transparent functions for users and burying inside all complicated research works in background
- Extended collection of related researches and literatures
- Summary/detail report documentation

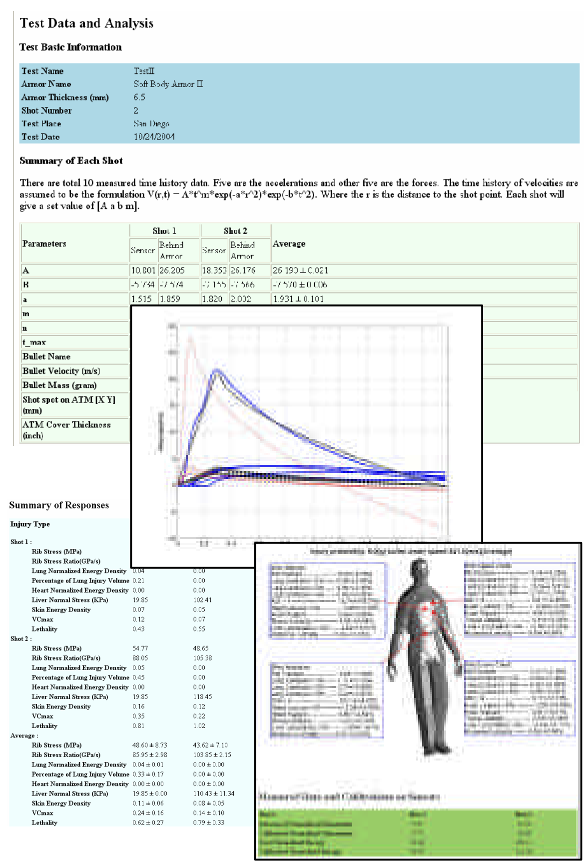
Product

--ATO-K Final Report, Part VI: ATM and BABTAP User's Manual, Fournier A., Zhang J., Report in preparation.

--Behind Armor Blunt Trauma Assessment Program, Web Application, Jonathan Zhang, Yuqing Niu, Weixin Shen, May 2005

When body armor defeats an impacting bullet by expanding and deforming, there is a transfer in kinetic energy from the body. This energy transfer creates blunt trauma to the underlying tissues by disrupting and damaging them. In this application, after the live fire test data imported, the behind armor loading estimation and reconstruction are conducted at first. A mathematical formulation is used to descript the back face velocity distribution over time and space and represented by several parameters. In the database of the application, there is a response lookup table from advanced finite element models. It connects the behind armor loading parameters and the human body responses, such as rib maximum normal stress, normalized lung and heart energy density, liver normal stress, skin energy density and some other global values, such as VCmax and Lethality. The data in this table are come from simulations of live fire tests and other virtual hundreds of ballistic cases. The biomechanically-based injury correlations are also included in this program. The blunt trauma injury probabilities and severities are obtained from the injury correlations and body responses. The report gives the summary injury results and detailed test data, reconstruction of loadings, body responses and injury probabilities of each shot.

In addition the injury assessment function, the program also provides the document archive capability and stores the library of armor, bullet and launchers for user to save their reports and manage their data. The literature database gives the ability for user to access related research works.



Behind Armor Blunt Trauma Assessment Program: Loading estimation and reconstruction, responses and injury summary.

The main steps using the program

- Conduct live fire test on ATM
- Input the test information (armor, bullet)
- Loading time history into the software in the client computer
- Run BABTAP analysis to give the report
- Report archived for future analysis
- Armor, bullet and weapon archived in libraries

Cited References:

Shen, W., Niu, Y., and Stuhmiller, J.H. (2005) "Biomechanically Based Correlations for High-speed Impact Induced Rib Fractures, Journal of Trauma 58(3), 538-545.

Shen,W., Niu,Y., Mattrey,R., Fournier,A., Corbeil,J., Yoko,K., and Stuhmiller,J.H. (2006) Development and validation of Subject-specific Finite Element Models for Blunt Trauma Study. Journal of Biomechanical Engineering, Accepted

Niu, Y., Shen, W., and Stuhmiller, J.H. (2006) Finite Element Models of Rib as a Beam Inhomogeneous Structure under High-speed Impacts. Medical Engineering & Physics, Accepted

BEHIND ARMOR CHARACTERIZATION

Significance

Current standard for BA signature that simply measures peak deformation in clay test is significant but insufficient to assess injury. Test and simulation results are indicating that adding additional dynamic measurements, especially the peak BA velocity and the time of reaching the peak, will greatly improve the assessment

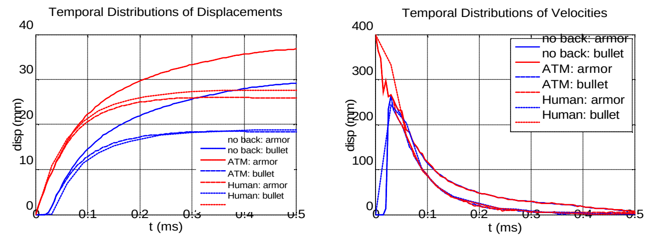
Product

--ATO-K Final Report, Part V: Characterization of Behind Armor Signatures and Blunt Injury Assessment with ATM, Lucy Bykanova, Eugene Niu, Adam Fournier, Weixin Shen., report in preparation.

Anthropomorphic Testing Modula (ATM) capable to withstand a significant number of ballistics impacts was developed as a surrogate device to characterize bullet-armor-body interaction. Total of 5 equally spaced accelerometer and FlexiForce sensor combination units are embedded inside the sensor block to measure impact force, ATM motion, and their distributions.

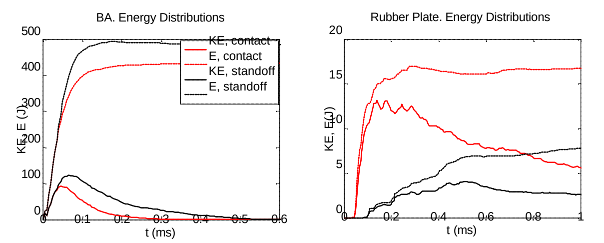
Advanced numerical modeling of bullet-armor-target interaction was applied for reconstructing impact signatures. Numerical models were tested and validated against a significant number of armor systems. FE modeling of Bullet-Armor-Target interaction provides comparative tools for determining responses to ballistic impact and has a potential to evaluate and improve body armor design and efficacy, determine human body injury and assist with injury prevention.

Character of bullet-armor interaction depends on backing material. Presence of backing material affects armor responses. ATM and human body produce the same effects on bullet-armor-target interaction and result in the same BA signatures. This conclusion is confirmed by FE modeling.



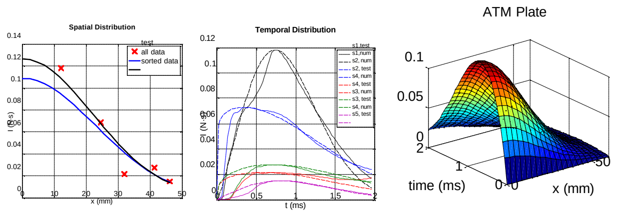
Effects of backing material on armor responses

FE simulations revealed the parameter that makes noticeable differences in BA and ATM responses. This parameter is standoff distance between BA and target. Standoff between body armor and ATM or other target provides with extra time in bullet-armor interaction that involves extra BA mass in process and reduces effective velocity and energy of the BBA impact.



Effects of standoff on armor and ATM plate energy distributions

Detailed analysis and systematization of results for live fire tests allows observation some regularity in sensor readings. Mathematical method can be developed to fit the test measurements and determine the impact signatures for specific armor systems. The temporal and spatial distributions of velocity, impulse, and energy are represented by simple mathematical functions. Shape functions can be extrapolated toward the surface based on analysis of tests results conducted with variation of rubber cover thickness and in combination with FE analysis.



Empirical approach for BBA signatures

Live fire tests using ATM were conducted to determine BA signatures from the measurements and to compare the results of these measurements with the results from laboratory clay test and numerical modeling.

Comprehensive analysis of BBA signatures for wide range of parameter variations was performed. Based on the simulations, an easy modification of the body armor was proposed which may result in significant reduction of blunt trauma probability. Validation of the proposed redesign was confirmed by results of live fire tests.

THORACIC AND ABDOMINAL FINITE ELEMENT MODELING AND APPLICATIONS

Significance

- Subject-specific and real anatomical geometry
- Validated by extensively experimental data
- Template-based mapping mesh
- Computational efficiency and accuracy

Product

--Biomechanically-based Criteria for High-speed Impact Induced Rib Fractures, Weixin Shen, Yuqing Niu and James H. Stuhmiller, J. Trauma, 58(3), 538-545, Jan. 2005.

--Finite Element Models of Rib as an Inhomogeneous Structure under High-Speed Impacts, Yuqing Niu, Weixin Shen and James H. Stuhmiller, submitted to Med Engr Phys, 2006.

--ATO Review Meeting Part IV: FE modeling and injury correlations, Yuqing Niu and Weixin Shen, Presentation, Jan, 2005.

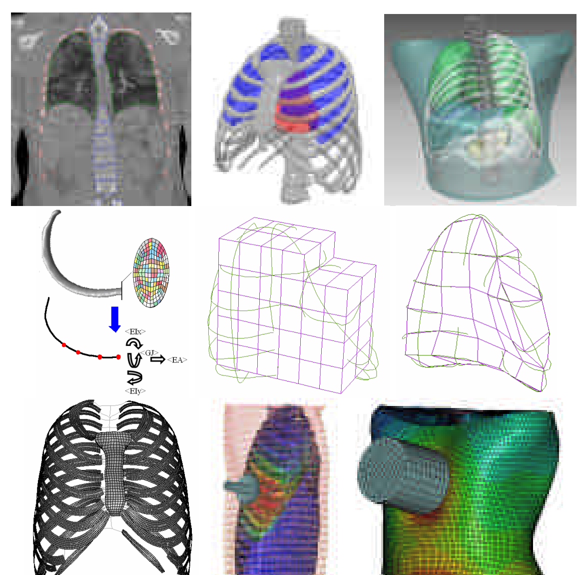
--Subject-Specific Finite Element Models of Swine and Human: Model development, validation and application, Yuqing Niu, Weixin Shen and Adam Fournier, Presentation, Jan, 2006.

--ATO-K Final Report, Part III: Development and Validation of Subject-specific Finite Element Models of Human and Animal, Yuqing Niu, Weixin Shen and Adam Fournier, report in preparation.

--ATO-K Final Report, Part IV: Biomechanically-based Thoracic and Abdominal Injury Correlations, Yuqing Niu, Weixin Shen and Adam Fournier, Report in preparation.

High-fidelity computational models such as finite element (FE) models that can accurately predict the mechanical response of the body to impacts is indispensable for this to be possible. Development of human or animal subject-specific virtual reality models that can simulate the occurrence and progression of blunt trauma injuries under a variety impact conditions will address many challenging issues, including (1) accurate representation of the complex anatomy of a subject; (2) good material characterization of bone and soft tissue materials at the rate of the impact loading; (3) numerical efficient and accuracy.

To address these issues, this study uses a systematic approach to develop and validate subject specific thoracic and abdominal models by combining animal testing and finite element modeling. Controlled animal tests were designed to provide high resolution CT images, chest wall motion, lung pressure, and pathological data. Reconstruction of the medical images allows the anatomical details of the rib cage, chest wall tissues, and thoracic and abdominal organs to be accurately modeled. Material properties of the rib cage components were directly determined from CT images and material parameters of soft tissues were selected from reported values. To reduce the computational cost and increase model accuracy, analytical formulations of ribs were developed and implemented in this model. Sensitivity analysis was conducted to identify the key materials and numerical parameters of the model and to remove extra parameters. Model validations are conducted by comparing the animal test data, including chest wall motions and lung pressures, the predicted and observed injury pattern. In addition, the frontal and side impact tests (Kroell et al. 1972, Viano et al. 1989) were used to validate the swine and human models.



Thoracic and abdominal finite element modeling (geometry reconstruction, smoothing, mesh template) and validation (animal tests, frontal and side impact test)

Injury criteria connect the relationships between tissue injuries and responses. The main thoracic and abdominal blunt trauma includes rib fractures, lung contusion, heart lesion, liver laceration and spleen bleeding. The biomechanically based injury criteria are developed from the finite element (FE) simulation and animal test studying. These injury correlations are based on the local stress or energy density and statistical analysis of comparisons between predicted injury and observed injury in experiments. The rib fracture and pneumothorax are determined by the normal stress or stress ratio of ribs. Lung contusion and heart lesion are decided by their normalized energy density. Liver laceration is determined by liver normal stress. These proposed injury correlations are given by the logistic regression curves and the fitting fineness demonstrates they successfully predict the injury pattern.

Cited References:

Kroell, C. K., Schneider, D. C., Nahum, A. M., 1972, "Impact tolerance and response of the human thorax", 710851, SAE 15th Stapp Car Crash Conference, New York, PP. 84-134

Viano, D. C., Lau, I. V., Asbury, C., King, A. I., Begeman, P., 1989, "Biomechanics of the human chest, abdomen, and pelvis in lateral impact", Accident Analysis and Prevention, 21(6), PP. 553-574

BIOMECHANICALLY-BASED INJURY CORRELATIONS

Significance

- Based upon extensive collection of injury data from animal and cadaver studies
- Stress/strain based correlations are more general and tend to be valid under a wide range of loading conditions
- Account for realistic injury mechanisms
- The FE models used to calculate tissue stress/strain were validated against a significant number of controlled test data, accounting for accurate geometry and material properties

Product

--Biomechanically-based Criteria for High-speed Impact Induced Rib Fractures, Weixin Shen, Yuqing Niu and James H. Stuhmiller, J. Trauma, 58(3), 538-545, Jan. 2005.

--Behind Armor Blunt Trauma Assessment Part III: FEM & Injury Correlation, Weixin Shen, Yuqing Niu and James H. Stuhmiller, Presentation, Aug. 2003.

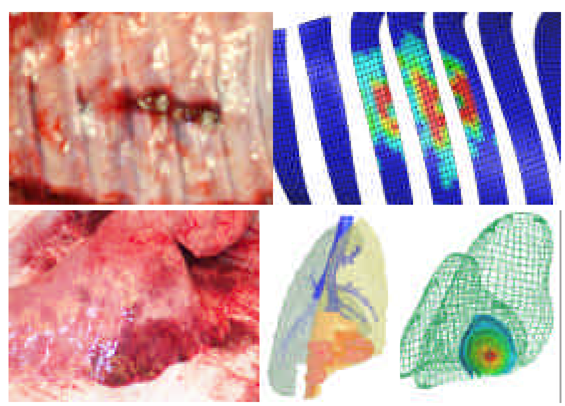
--ATO Review Meeting Part IV: FE modeling and injury correlations, Yuqing Niu and Weixin Shen, Presentation, Jan. 2005.

--ATO-K Final Report, Part IV: Biomechanically-based Thoracic and Abdominal Injury Correlations, Yuqing Niu, Weixin Shen and Adam Fournier, Report in preparation.

Injury criteria connect the relationships between tissue injuries and medical responses. The main thoracic and abdominal blunt trauma includes rib fractures, lung contusion, heart lesion, liver laceration and spleen bleeding. In the automobile industry, the injury criteria are mostly based on the measured global mechanical response, such as thoracic compression, lateral chest wall and spine acceleration and viscous criterion (VC). However, for small projectile and the high speed impacts, the body responses are localized and injury criteria developed for big mass and low speed impacts can not be directly applied to study the blunt trauma induced by high speed impacts.

In this study, the biomechanically based injury criteria are developed from the finite element (FE) simulation and animal test studying. These injury correlations are based on the local stress or energy density and statistical analysis of comparison between predicted injury in simulations and observed injury in experiments. The rib fracture and pneumothorax are determined by the normal stress or stress ratio of ribs. Lung contusion and heart lesion are decided by their normalized energy density. Liver laceration is determined by liver maximum normal stress. These proposed injury correlations are given by the logistic regression curves and the fitting fineness demonstrates they successfully predict the injury pattern.

The injury criteria will provide a standardized method for assessing the risk and severity of injury and determine the mechanism of injury. The existed criteria are mostly based on the subject global response, such as, deformation, velocity and acceleration under low speed, big mass impacts. The subjects generally have significant global deformation and motion. However, there are very little global deformation and movement of the subject under high speed, small mass impacts. The deformation is concentrated on the local under the impact location and the motion wave will through the subject body.



Ribs fracture pattern and FE calculation of normal stress distribution; Lung contusion patterns from necropsy pictures and reconstruction of post-impact CT images and FE calculation of pressure distribution;

The global deformation and speed are very tiny and the local deformation and speed are very high. For development of injury criteria of high speed, small mass impacts, two main issues have to be considered, subject independency and loading independency. The subject independency means that the injury criteria can be applied in any subjects with different size, shape and weight. The loading independency indicates that the criteria can be used to assess injury under any kinds of impacts, without considering the non-lethal projectiles or the bullet striking penetration –proof armors.

These criteria of blunt trauma are developed in this research

- Rib Fracture
- Lung Tissue Injury
- Heart Lesion
- Liver Laceration
- Pneumothorax

Cited References:

Kroell, CK, Schneider, DC, and Nahum, AM, Impact Tolerance of the Human Thorax II, 1974.

Lau VK, Viano DC, 1981, Influence of impact velocity and chest compression on experimental pulmonary injury severity in rabbits, Journal of Trauma, 21(12), PP. 1022-8

Miller MA, The biomechanical response of the lower abdomen to belt restraint loading, Journal of Trauma, 29(11), PP. 1571-84, 2005

Tarriere, C, Walfisch, G, Fayou, A, Rosey, J, Got, C, Patel, A, and Deluias, A, Synthesis of Human Tolerances Obtained from Lateral Impact Situations, 1979. Paris

Viano DC, Lau VK, 1983, Role of impact velocity and chest compression in thoracic injury, Aviation Space and Environmental Medicine, 54(1), PP. 16-21

UCSD LARGE ANIMAL STUDY

Significance

Collect high-quality controlled test data for develop FE model and injury correlations, including

- Subject-specific anatomical data
- Mechanical response data
- Physiological measurements
- Pathology data

Product

--ATO-K Final Report, Part II: Animal Responses and Injuries due to Behind Armor Impacts, Shen, W., Fournier, A., Niu, E., et al, Report in preparation

--ATO-K large animal test dataset.

The animal study used instrumented impactor that varies in mass and impact speed to deliver a load similar to behind armor impact onto the animal subjects. Swine subjects with various sizes were used.

The animal tests features

- High quality controlled testing
- Accurate mechanical response data during impacts
- High resolution whole-body CT image before and after impact
- Key physiological parameters
- Pathological data from necropsy
- Post-CT imaging of distribution of tissue damage
- Histology of tissue to give information on injury mechanism
- A significant number of tests to provide statistical significance

The following test procedure was followed for each test

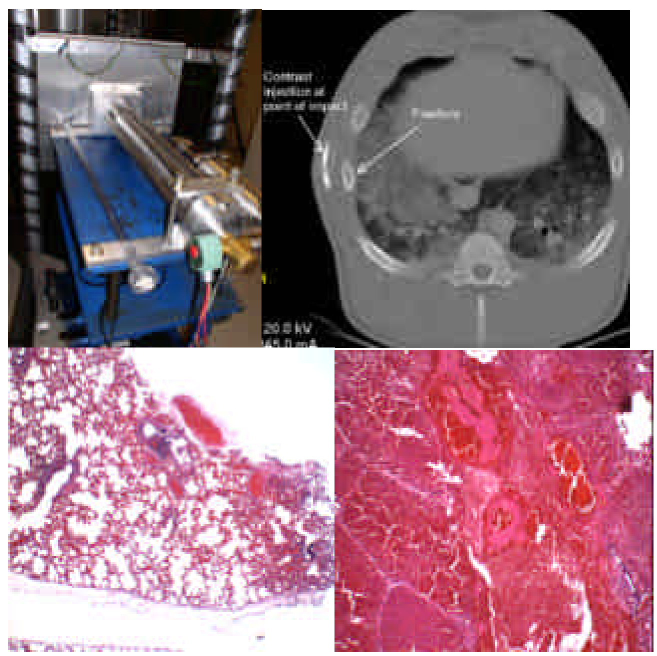
- Care of animal
- Ultrasonic study
- Insertion of pressure catheters into lungs:
- Pre- exposure imaging
- Impact: force and response data
- Ultrasonic study
- Post-exposure imaging
- Necropsy: injury data and assessment
- Histological samples

The major injuries studied included:

- Thoracic: rib fracture, pneumothorax; lung contusion, heart injuries
- Abdomen: liver, spleen laceration

Main injury findings were summarized as

- Skin lesion 100%
- Pneumothorax 10%
- Rib Fracture 60%
- Lung Contusion 90%
- Liver Laceration 20%



communications

ATM & Live Fire Testing

Significance

An experimental device was produced that, when used with the proper assessment models, can evaluate and help develop lighter and safer body armor systems.

ATM is more effective at characterizing the behind armor impact signatures and their resultant injury potential than current testing methods.

Product

--ATM testing apparatus

--ATO-K Final Report, Part VI: ATM and BABTAP User's Manual, Fournier A., Zhang J., Report in preparation.

Anthropomorphic Test Module (ATM) was developed and used in live fire tests to measure the spatial and temporal distribution of forces and motions under a variety of firing conditions and hit locations on body armor systems. The ATM allows similar deformation as a real human; the measured ATM responses to impact are compatible to those of humans. The design features of the ATM include:

Frame Design

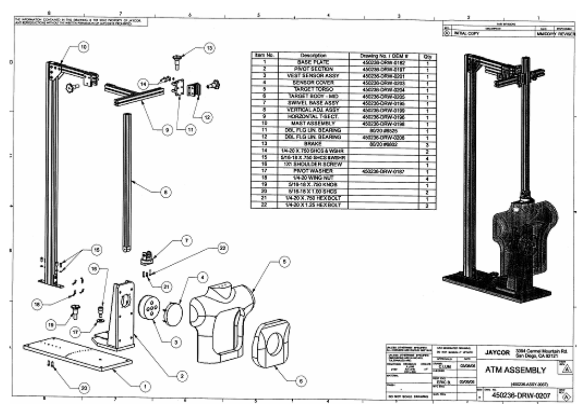
1. Outline of human torso using a polyurethane based compound allows for live tissue stimulant of human form
2. Additional back support gives natural curvature to torso so vest can be tested in the manner it is actually worn
3. Mobile platform allows for easy transportation as a single unit
4. Hand driven wing nuts simplifies the assemblage of ATM

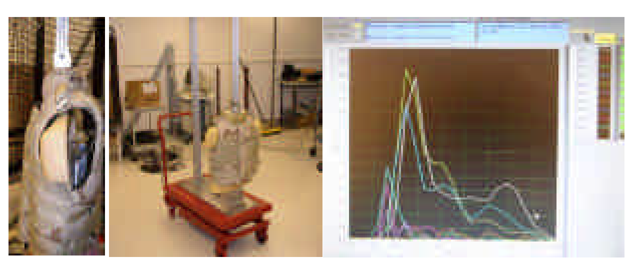
Testing Features

1. Sturdy frame provides sufficient support to vest during testing
2. Supports angled shot rotation at 5 degree increments up to ±30 degrees
3. Vertical and horizontal translations allows easy choices for impact locations
4. Torso rotation matches the rotation of ATM sensor mounting
5. Torso inserts give a seamless transition between ATM and torso unit.
6. Sensors are protected by rubber cover plates ranging from 0.5" to 1.5"

Data Acquisition

1. 10 channels of behind armor motion and force measurements at +50kHz sample rate
2. Chronograph measurements of bullet impact velocity
3. High speed camera recording the bullet-armor intervention
4. Fuji film details the back face signature of the armor against the ATM
5. The test procedure is made up of pre-impact preparation, impact test, and post-impact recording.
6. Pre-impact



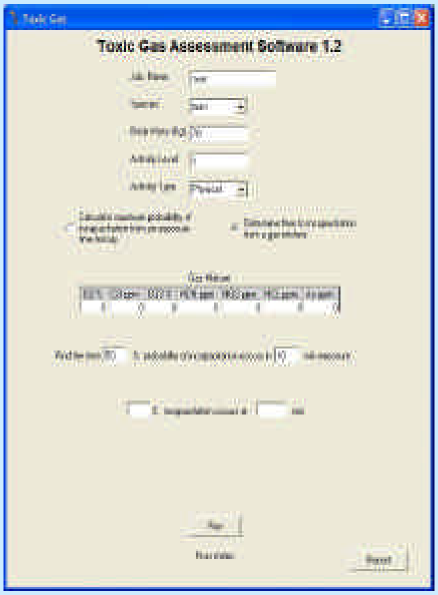


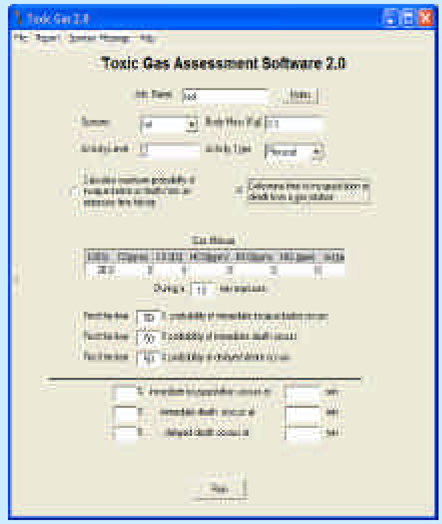
7. Connect sensor with DAQ system
8. Select armor and bullet combination
9. Select ATM cover
10. Select shot location and torso insert
11. Select angle of shot
12. Aim and predetermine hit location
13. Fit armor to ATM

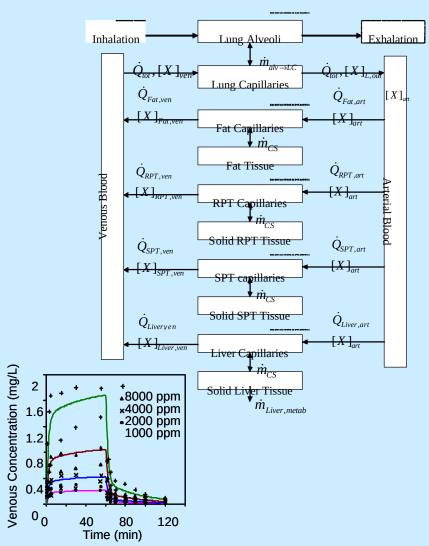
Impact test
1. Check sensors and DAQ software
2. Check chronograph, Fuji film and HS video camera
3. Ballistic firing

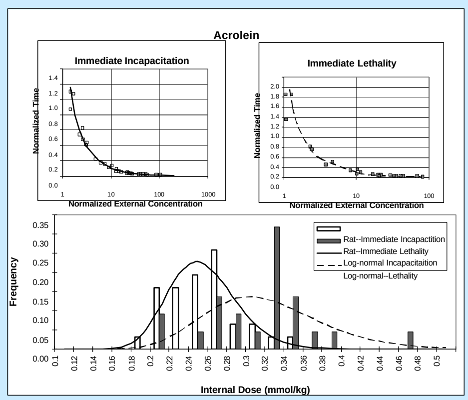
Post-impact
1. Record time traces, pictures, movies
2. Run assessment software to evaluate armor performance

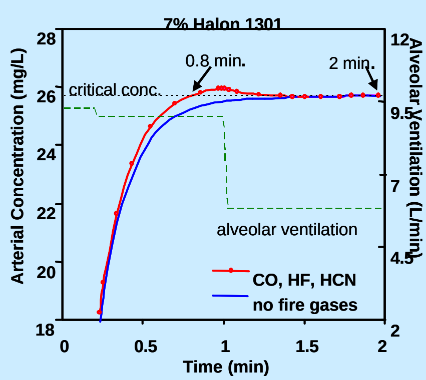
4. Inhalation Toxicology Research

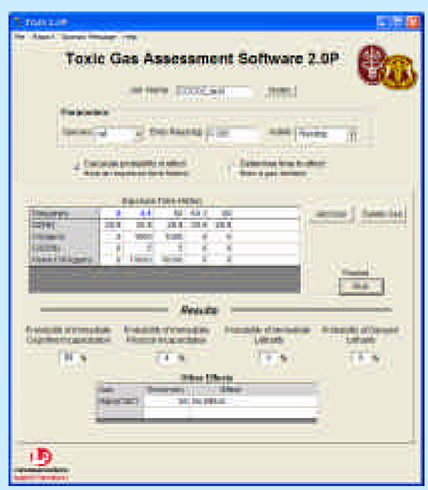












INCAPACITATION SOURCE BOOKS

Significance

Jaycor employs a research strategy in developing physiological models that is based on an initial, thorough review of the literature to understand and critically evaluate mechanisms of action, existing experimental data, and previous models. Based on these reviews, captured in Source Books, a model development and validation plan is developed. These Source Books review the models and theories of acute toxic gas effects and define the source of all previous animal tests on incapacitation and lethality.

Product

--Immediate Incapacitation Source Book, Stuhmiller, L., Report J3150.12-01-113, April 2001.

--Acute Toxic Effects Data Book, Report J3150.12-02-138, April 2001.

This report provides a synthesis of the literature on toxicity from inhalation of gases, with an emphasis on mechanisms, data, and models dealing with immediate incapacitation. This review provides the guidance for developing the first mathematical model in the series, TGAS 1.0, which will provide an estimate of immediate incapacitation from acute exposure to complex mixture of toxic gases.

Almost all literature data on acute exposure tests are rodent data. The existing data only provide simple correlates of incapacitation or lethality with external concentration and duration without key parameters, such as ventilation rate, blood chemistry, and even body mass, are not reported.

The tests that have been conducted have differing test conditions and end points. For example, in the rodent tests, some are restrained in a tube and some are exercising on the rotating wheel. Their ventilation rates, although not reported, are certainly different in these cases. Incapacitation is variously defined as failure to stay on a moving wheel, failure to avoid shock, or failure to move for a certain period of time. In the limited number of primate tests, incapacitation is based on escape, which is cognitive as well as physical. The tests conducted by the FAA, however, were the most completely documented, with the same test conditions and end points, and a wide range of toxic gases. Only four studies reported in the literature considered incapacitation during combined gas exposures, limiting the amount of data on gas interactions. Fortunately, the FAA conducted three of those four studies.

Data on important physiological effects of toxic gas inhalation, especially ventilation, come from other experiments that were not measuring incapacitation. Generally, all species have increased ventilation in reduced oxygen or increased carbon dioxide atmospheres, although the magnitude of the effect differs between species. Hyperventilation under acute hydrogen cyanide exposure has been observed in both rats and primates, probably because of a hypoxic reaction to the interference with oxygen unloading from hemoglobin. A similar increase in ventilation in rats has been reported at moderately high carboxyhemoglobin levels, but ventilation decreases at extremely high levels. Irritant gases tend to increase ventilation in large species, but decreases ventilation in rodents.

The only truly physiologically based model describing toxic gas inhalation is the Coburn-Forster-Kane (CFK) model for CO. The model predicts the creation of carboxyhemoglobin, accounting for the competition of carbon monoxide and oxygen for the hemoglobin bonding sites. The model has been extended to include effects of ventilatory response to oxygen and carbon dioxide, variation of parameters among species, acid-based effects, and exercise effects on metabolism, ventilation, and cardiac output. The model has been compared with data from a wide range of species and exposure conditions.

For all of the other toxic gases, only empirical correlations of the time to incapacitation with external concentration have been proposed. This type of dose response data provide no means to extrapolate among species because the correlations do not account for body mass, blood chemistry differences, ventilation differences, exercise effects, temperature, altitude, or any other reasonable parameter.

The existing mixed gas model (The Fractional Effective Dose model, EFD) estimates toxic effect of a combined gas based on the assumption that the individual dose divided by their EC50 values can be summed. These "dose-additive" models implicitly assume that all toxic substances follow the same pathway to the same endpoint, ignoring the difference in nature of narcotics and irritants, or interactions among them. This simple mixed gas model assumes that any time this sum reaches 1 the incapacitation or lethality will occur. If the effect occurs when the sum is less than 1, the toxic effect is defined as synergistic, and if the toxic effect occurs when the sum is more than 1, the toxic effect is defined as antagonistic. The FAA proposed a comprehensive FED model for incapacitation, while Levin proposed one for lethality.

We conclude that, first of all, a multiple toxic gas effects model must be based on the internal dose absorbed, not by the external concentration. To calculate internal dose, a physiologically based breathing control model must be included to assess the ventilation rate. The ventilation calculated results could then be extrapolated among species. The internal dose should be normalized by the body mass to produce a specific dose (mg/kg) in the form normally used to estimate toxic effects. Effects, such as incapacitation, should be correlated to this estimated internal dose per body mass.

Secondly, the interactions between species should be derived from appropriate data. However, this is problematic given that there is so little experimental data exist concerning mixtures. To our knowledge, there is perhaps only one set of data (Ballantyne 1987, CO-HCN) available for estimating interactions of mixed gas.

Lastly, the toxic effect of narcotics and irritants should be computed by law of probability for independent events, which estimates the total effects of events with unrelated nature.

$$P(D1, D2, D3, \ldots) = 1 - [1 - P(D1)] \times [1 - P(D2)] \times \ldots$$

These concepts, plus the experimental data collected and digitized, form the basis for developing and testing the TGAS 1.0 model for immediate incapacitation.

TGAS 1.0

Significance

Brief exposures to high concentrations of toxic gases from fires can cause immediate incapacitation and post-exposure injury. Quantifying the hazard is necessary to evaluate human escape and survival and to determine the effectiveness of protection systems. TGAS 1.0 is a tool for determining the risk of immediate incapacitation from any combination of seven fire gases.

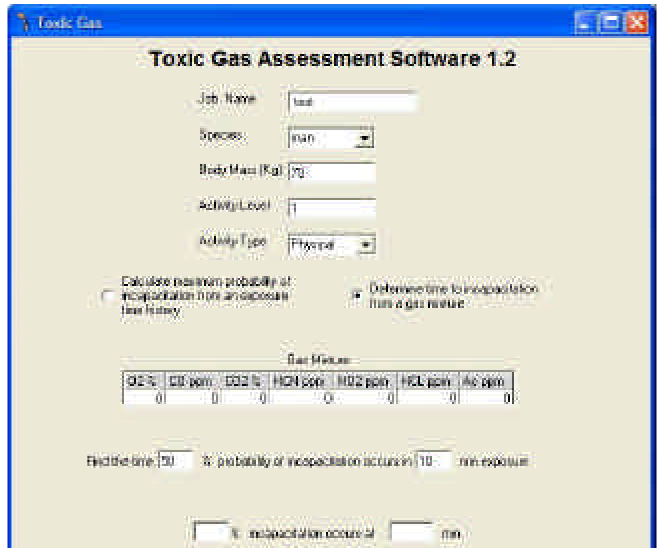
Product

--Toxic Gas Assessment Software, version 1.0, Diane Long, 2002.

--An internal dose model for interspecies extrapolation of immediate incapacitation risk from inhalation of fire gases. Stuhmiller, J.H. and Stuhmiller, L.M. Inhal. Toxicol., 14:929-957 (2002).

A quantitative model for predicting immediate incapacitation from inhaled toxic gases has been developed. The model calculates internal dose normalized by body mass to allow extrapolation from small animal to man. Ventilation changes due to species, activity level, and chemically-induced response are accounted for by fitting data reported in the literature. The probability of incapacitation for single gas exposures is estimated as a function of the normalized internal dose. The probability of incapacitation for a mixture of gases is determined by the rule for combining probabilities of independent events. The model predictions compared well with animal incapacitation data for both single and combined gases. The conservatism of proposed thresholds for military personnel was also discussed.

The model underscores the critical role played by ventilation in determining toxic gas incapacitation. The ventilation to body mass ratio is nearly five times greater in rats than man, suggesting that, based on that factor alone, man can tolerate a much higher external concentration for acute, short duration exposures. Compounding this effect, however, is the observation that the ventilation response to chemical exposure is very different in large and small animals. In particular, large animals often show an increase in ventilation when exposed to irritant gases, while small animals often show a decrease. Ventilation consideration is a key factor in internal dose determination.



Toxic Gas Assessment Software Screen

The model estimates of the tolerance of man to acute toxic gas exposure are in line with proposed concentrations of carbon monoxide, but suggest that man can tolerate much higher than proposed concentrations of the other gases without becoming incapacitated. Lower tolerances, however, may be appropriate when long term lung injury from irritant gases is considered. Development of correlates of internal dose with lung injury and lethality in small animals would provide more specific information on human tolerance.

The TGAS 1.0 software provides a quantitative means of estimating immediate incapacitation from acute exposures to mixture of toxic gases that is consistent with all data examined. The model provides a structure for systematically adding improved models of these effects and, therefore, improved estimates of the risk to man. These estimates can be used to judge the efficacy of protective systems and the ability of individuals to escape and protect themselves from fire gases.

TGAS 2.0

Significance

TGAS 2.0 software extends the previous version to allow the assessment of both immediate and delayed lethality from the inhalation of fire gases. Survival depends on both being able to escape the immediate hazard and not suffering a delayed death. TGAS 2.0 allows both components of survival to be quantified as probability of occurrence for any combination of seven, common fire gases.

Product

--Toxic Gas Assessment Software, version 2.0, Diane Long (2005).

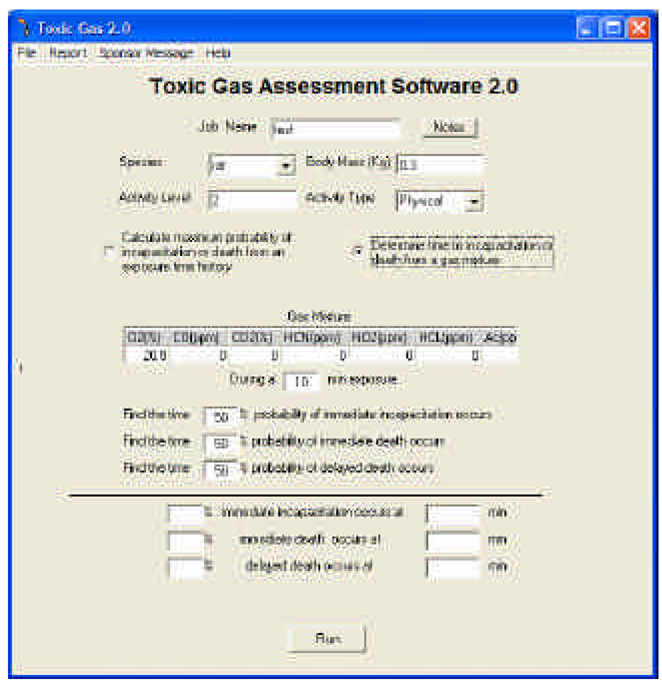
--An internal dose model of incapacitation and lethality risk from inhalation of fire gases, Stuhmiller, J. H., Long, D. W., and Stuhmiller, L. M., Inhal. Toxicol. 18(5), 2033-44, 2006.

A quantitative model for predicting immediate incapacitation and lethality and delayed lethality from inhaled toxic gases has been developed. The model, TGAS 2.0, calculates internal dose normalized by body mass to allow extrapolation from small animal to man, accounting for ventilation changes due to species, activity level, and chemically-induced response. The probability of outcome for single gas exposures is estimated as a function of the logarithm of the normalized internal dose and the probability of outcome for a mixture of gases is determined by the rule for combining probabilities of independent events. The model predictions compares well with animal data for both single and combined gases. A rational approach to establishing human thresholds that accounts for all outcomes and probability of occurrence is also discussed.

The model underscores the critical role played by ventilation in determining toxic gas incapacitation. The ventilation to body mass ratio is nearly five times greater in rats than man, suggesting that man can tolerate a much higher external concentration for short duration exposures. Compounding this effect, however, is the observation that the ventilation response to chemical exposure is very different in large and small animals. In particular, large animals often show an increase in ventilation when exposed to some irritant gases, while small animals often show a decrease. Furthermore, ventilation changes can take place over a time that is comparable to the acute exposure conditions considered. There is a great need for better ventilation response data in both animals and man so that internal dose extrapolation can be better accomplished.

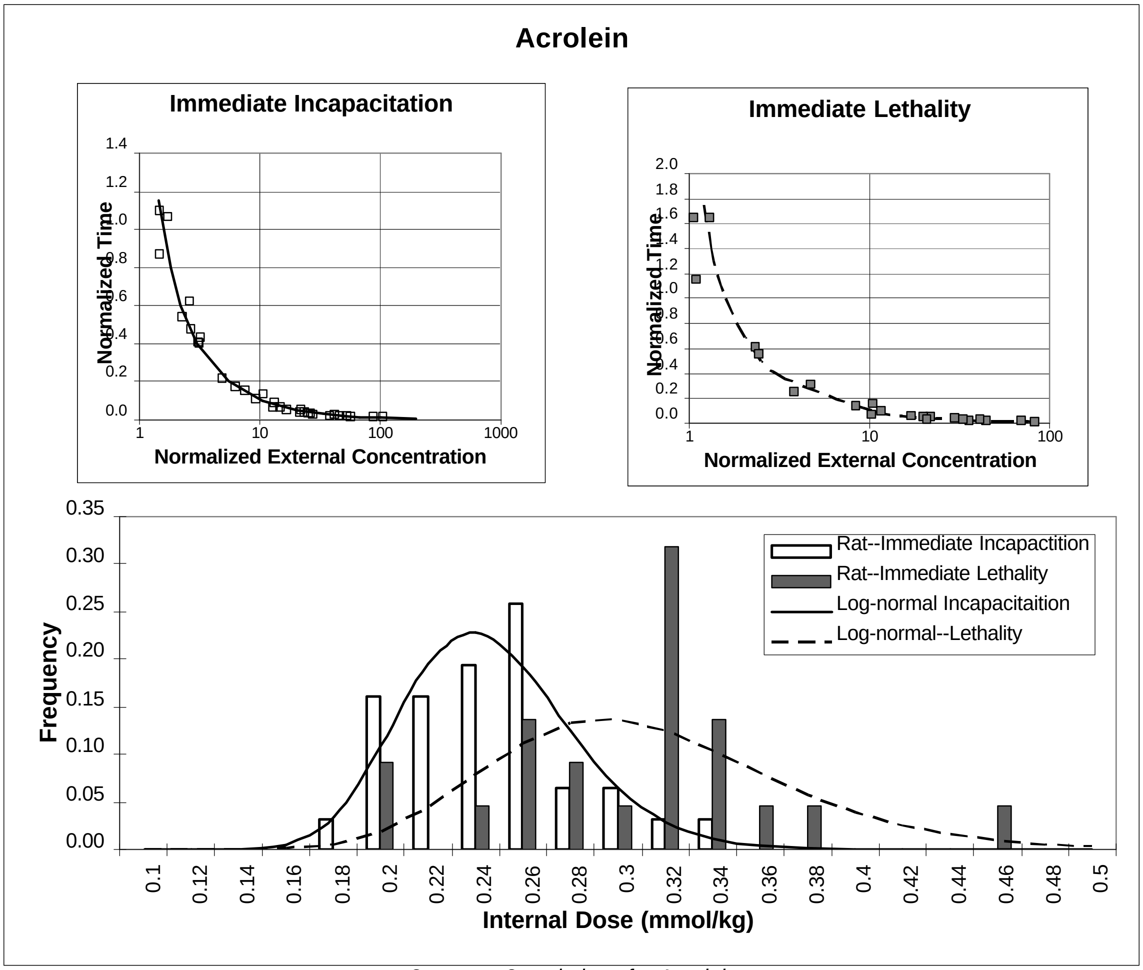
The TGAS 2.0 estimates both the incapacitation and lethality responses of man to acute toxic gas exposure, which is required in making an overall survivability estimate. The model also provides an estimate of the dose-response curve, which is required in establishing tolerances for man in occupational situations.

TGAS 2.0 unifies about 4000 animal test results and provides a rational means to extrapolate animal data to man. These estimates can be used to judge the efficacy of protective systems and the ability of individuals to escape and protect themselves from fire gases.



TGAS 2.0 Input Screen

communications



Outcome Correlations for Acrolein

PBPK Source Books

Significance

Jaycor employs a research strategy in developing physiological models that is based on an initial, thorough review of the literature to understand and critically evaluate mechanisms of action, existing experimental data, and previous models. Based on these reviews, captured in Source Books, a model development and validation plan is developed. These Source Books define the PBPK models that form the basis of the TGAS-2P software.

Product

--Physiologically Based Pharmacokinetic Modeling Source Book, Stuhmiller, L., Report J3150.12-05-260, Oct. 2005.

--PBPK Models for Halocarbons Source Book, Stuhmiller, L.,Report J3150.12-05-261, Oct. 2005.

--Halocarbon Regulations Source Book, Stuhmiller, L., Report J3150.12-05-262, Oct. 2005.

The goal of this project is to review the literature related to the physiologically based pharmacokinetic modeling (PBPK) in order to guide the development and validation of the assessment software.

PBPK models are the kinetic models of the uptake, disposition, metabolism and elimination of chemicals based on rates of biochemical reactions, physiological and anatomical characteristics. PBPK models are sometimes referred to as physiological toxicokinetic (PT) models to emphasize their application with compounds causing toxic responses. Pharmacokinetics (or toxicokinetics) is the study of the time course for the absorption, distribution and elimination of a chemical in a biological system (Clewell and Andersen, 1985), whereas pharmacodynamics is the study of the time course biological response due to exposure to a chemical (i.e., carcinogenicity and teratogenicity).

The burgeoning use of PBPK models in toxicology research and chemical risk assessment today is primarily related to their ability to make more quantitative predictions of target tissue dose. PBPK models are currently among the most accurate models available for exposure response extrapolations between routes, between species, and between dose levels within the specie. It is a powerful tool for providing insights to human kinetics and guidelines for rational medical and regulatory decisions making. The PBPK simulation models have been used in the biological exposure monitoring and medical surveillance of exposed workers, reference dose calculating for regulatory agencies, the planning of clinical trials from early human data, drug discovery, candidate selection, drug development. The current use of PBPK models range from relatively straightforward application requiring the extrapolation of chemical kinetics across species, route, and duration of exposure to much more demanding chemical risk assessment applications requirements of a description of complex pharmacodynamic phenomena such as mitogenicity and hyperplasia secondary to cytotoxicity.

The potential advantages of PBPK modeling are many. The basic model can be tailored to describe various scenarios (such as activity, high altitude, high or low temperature etc.) by adjusting the parameter values. Parameter input offers flexibility in handling kinetics and metabolism variability in different species and individual humans. It can integrates all available data in one setting allowing animal data and in vitro human data to be used together in the predictions. Since the method takes into account of metabolism, the interactions of the mixture gases in the body could be accounted for by properly describing the biopathways for each chemical in the mixture environment. Because these models require very specific information, much of which can be obtained in vitro, they are much less dependent on extensive animal experiments than conventional risk assessment methods. Although some in vivo animal experimentation will always be necessary, fewer animal data are needed to test the accuracy of the model than the conventional approach.

Cited References:

Clewell, H. J., III, Andersen, M. E., (1985). "Risk assessment extrapolations and physiological modeling," Toxicol Ind Health, 1(4), 111-131.

PHYSIOLOGICALLY-BASED PHARMACOKINETIC MODELING

Significance

This work expands the ability to estimate the debilitating effects caused by secondary, volatile gases released in explosions and fires. The PBPK model developed unifies previous models into a single form, with a single set of physiological parameters, that can reproduce experimental data on effects from 22 volatile gases. Critical internal dose values are determined for each gas, which allows small animal tests conducted under simple exposure conditions to be extrapolated to man and to any exposure time-history.

Product

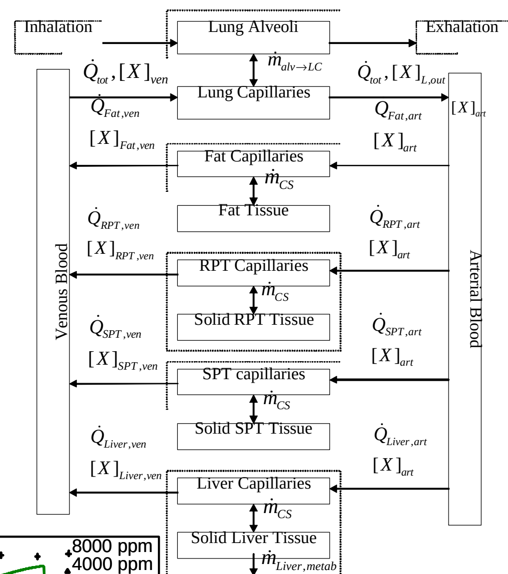
A Generalized Physiologically Based Pharmacokinetic Model Incorporating Acute Dynamic Ventilation Changes, Ng, L. J., Stuhmiller, J. H. and Stuhmiller, L. M., Inhal. Toxicol. 2006 (in press).

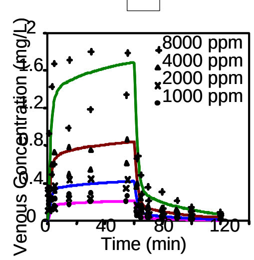
The goal of physiologically based pharmacokinetic (PBPK) modeling is to establish safe exposure levels based on internal dose limits. The use of internal dose as the metric allows animal data to be extrapolated to human, allows extrapolation between exposure levels, and establishes safety limits for all modes of entry, such as inhalation, skin absorption, ingestion, or bolus injection. Due to the prevalence of potentially harmful volatile chemicals found in the environment, an inhalation model for acute exposure was developed.

The body is modeled with seven compartments: the lungs, the richly perfused tissues (e.g. kidneys, brain), the slowly perfused tissues (e.g. muscle), the fat, a metabolizing liver, a pool of arterial blood, and a pool of venous blood. The inhaled chemical enters the lungs and equilibrates immediately with the blood. The blood travels through the arteries and gets fractioned between the compartments, where chemical is deposited into the tissue. The blood is collected in the veins and gets sent back through the lung capillaries. The amount of chemical transferred from air to blood or blood to tissue is dependent on the partition coefficients.

Unlike a number of current PBPK models that use a range of values for physiologic input parameters to produce results that fit experimental data, we define a common set of physiologic parameters for rat and human. The model was validated against experimentally measured blood concentrations for twenty-one volatile chemicals ranging from halogenated halocarbons to petroleum halocarbons to anesthetic compounds. The model proved to be accurate for all gases tested.

Critical internal dose levels were calculated corresponding to exposure time and atmospheric chemical concentration that produced deleterious effects as specified by LOAEL (lowest observed adverse effect level) or AEGL-2 (acute exposure guideline levels).





Schematic of the seven compartment PBPK model with an example of internal dose output from inhalation of a gas at four exposure concentrations.

communications

TGAS 2.0P

Significance

In a fire, in addition to the fire gases that are released, many volatile gases are present that can also threaten life and survivability. The TGAS 2.0P software extends previous software versions to compute the deleterious effects of these other volatile gases. One important class of gases includes the fire suppressant substances, such as Halon. The formulation is built upon physiologically based pharmacokinetic modeling, to which more gases can be added in a systematic way.

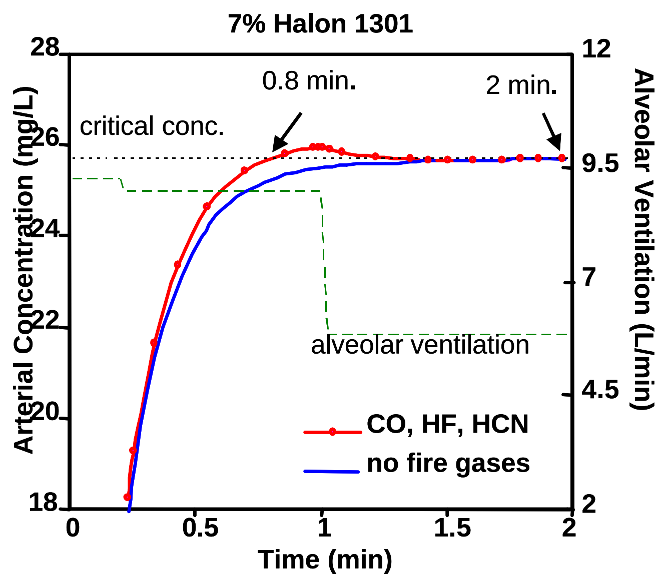
Product

--TGAS 2.0P Model, Laurel Ng (2006).

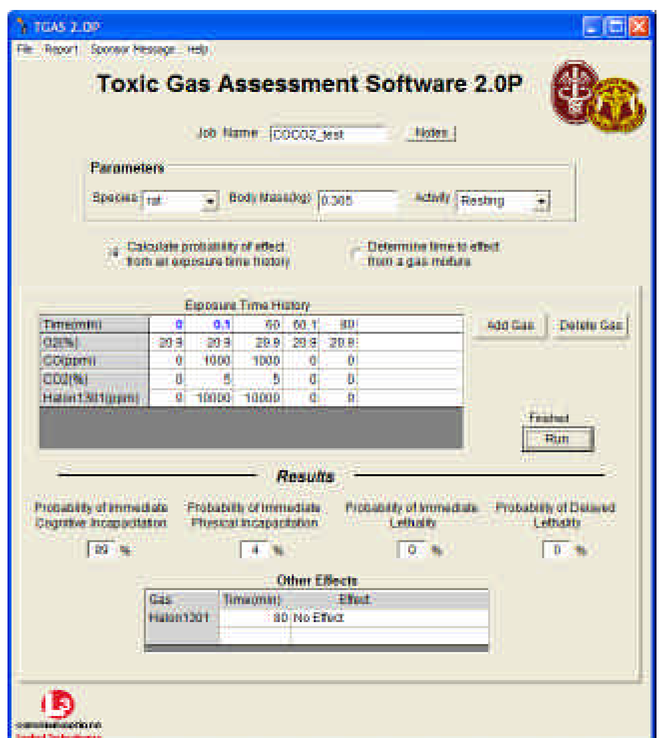
--A Generalized Physiologically Based Pharmacokinetic Model Incorporating Acute Dynamic Ventilation Changes, Ng, L. J., Stuhmiller, J. H. and Stuhmiller, L. M., Inhal. Toxicol. 2006 (in press).

The PBPK model described elsewhere is combined with the TGAS 2.0 model for fire gas response and outcomes. The combined model accounts for all sources of transient ventilation change: exertion, chemical stimulation, species, and body mass; and relates all outcomes to body-mass normalized internal doses.

The model allows the user to input species, body mass, and an acute, transient exposure profile for up to 29 different gases. The software computes the probability of incapacitation, lethality, or other deleterious effects, when a transient exposure is given, or it computes the time to an endpoint, when a gas mixture is given.



Internal dose comparison plot



TGAS 2.0P input screen

BREATHING CONTROL SOURCE BOOKS

Significance

Jaycor employs a research strategy in developing physiological models that is based on an initial, thorough review of the literature to understand and critically evaluate mechanisms of action, existing experimental data, and previous models. Based on these reviews, captured in Source Books, a model development and validation plan is developed. This Source Book reviews the models, mechanisms, and data related to the control of respiration.

Product

--Control of Respiration Source Book, Stuhmiller, L., Report J3150.12-01-141, May 2001.

The US Army Medical Research and Materiel Command (MRMC) has responsibility to conduct research that will support the assessment of immediate incapacitation and injury caused by acute exposure to toxic gases, particles, and aerosols. The assessment must account for physical activity, environmental conditions, and complex mixtures of gases. The Military Operational Medicine Research Program (MOMRP) is conducting a research program to develop a mathematical model of the physiological response to acute toxic gas exposure that will provide a standard means to estimate these effects. That program is called Scientific and Technical Objective Y: Inhalation Injury and Toxicology Models.

The model will be developed in incremental steps. The first version of the model will provide a means of estimating immediate incapacitation in man, employing empirical relations for key physiological processes. Successive improvements to the model will add more complete physiological models of breathing, blood, chemistry, airway transport and deposition, metabolism and so forth as required to capture the necessary mechanisms.

The technical approach to achieve this objective is to (1) assess the literature for mechanisms, models, and data pertinent to the particular phase of model development; (2) implement mathematical models incorporating those mechanisms and validate by those data; and (3) conduct animal studies to provide missing physiological parameters or needed confirmation results. This approach will be repeated for each increment of the model development.

In the first version of the toxic gas exposure model (TGAS 1.0) a method of approximating the internal dose, based on empirical relations, was proposed. Dose was normalized by animal body mass to account for the size variation. Ventilation parameters in the equation account for species differences, dead space mixing and activity levels. The results showed that the empirical relations captured the ventilation trends reported in the literature. However, this simple approach cannot provide a rational means to scale the results from animal to man, and lacks the parameters to describe the internal dose or interactions between toxic gases because it is not a physiologically based model.

TGAS 2.0 will be physiologically based, providing means to describe internal dose, interactions between toxic gases, and allowing species extrapolation and performance estimation. An accurate internal dose assessment requires a physiologically based breathing control model which estimates the ventilation changes as a function of the gas transport process, brain control mechanism, and sensor inputs.

Several research groups have assembled comprehensive models of breathing control, each with slightly different component models and each applied to slightly different problems. The control of respiration involves the interaction of many of the body's major systems (ventilation, circulation, metabolism, blood chemistry, neural and muscular control) and therefore requires a complete, interacting description. A composite model, using the best parts of these models, provides the starting point for TGAS 2.0.

This report provides a synthesis of the literature on control of breathing, with emphasis on identifying mechanisms, data, and models that are relevant to ventilation changes that can significantly impact acute inhalation exposures.

DYNAMIC PHYSIOLOGY MODEL 1.0

Significance

Ventilation changes due to internal chemical reactions or exertion have a significant effect on the prediction of toxic gas response, in particular, and physiological response, in general. The DPM is a mathematical model of critical physiological processes involved in toxic gas ventilation responses, hypoxia, and environmental stressors.

Product

--Dynamic Physiology Model 1.0. J.H. Stuhmiller (2005).

--A mathematical model of ventilation response to inhaled carbon monoxide, Stuhmiller, J.H. and L.M. Stuhmiller. J. Applied Physiology, 98:2033-2044 (2005).

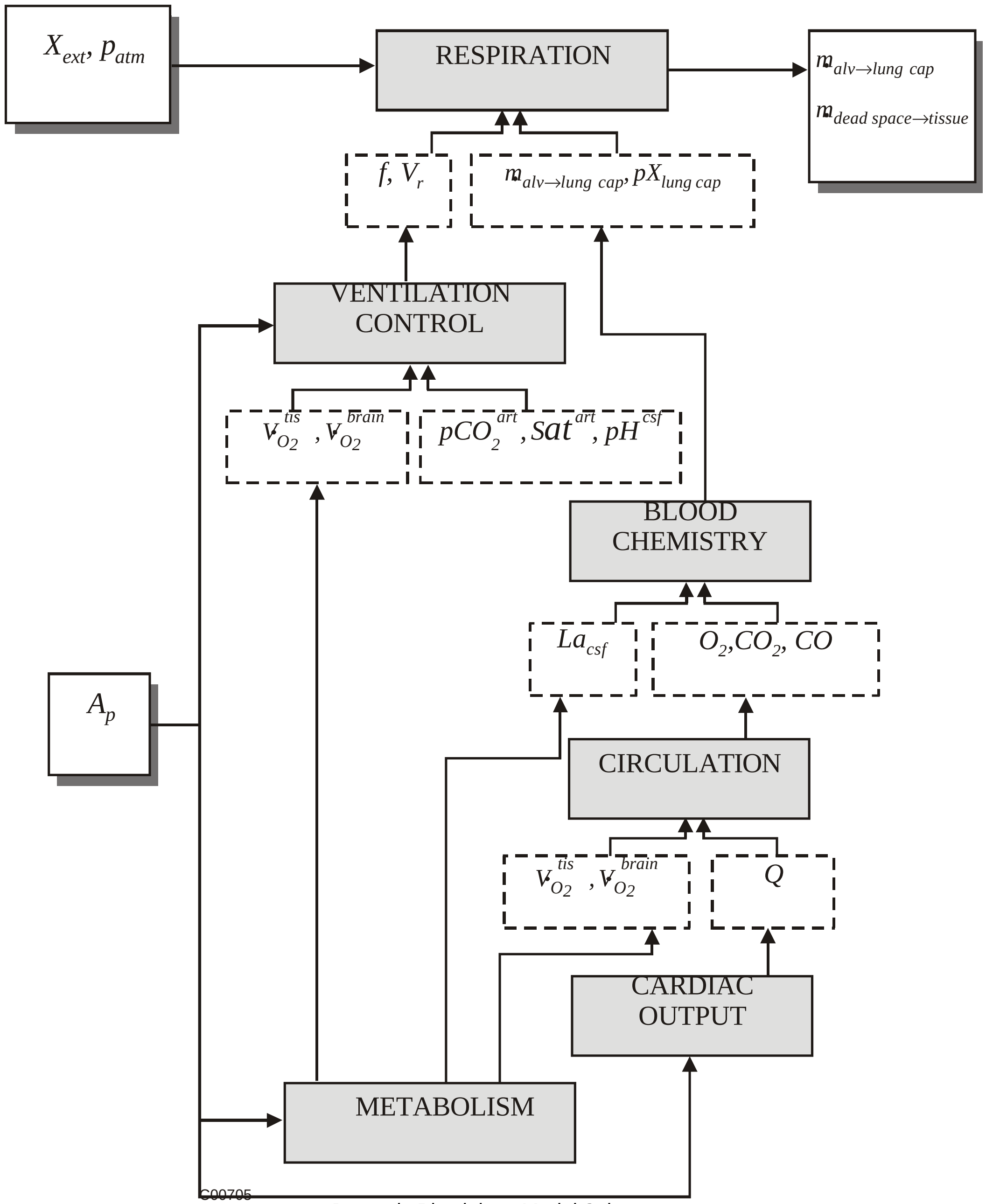
A comprehensive mathematical model, describing the respiration, circulation, oxygen metabolism, and ventilatory control, is assembled for the purpose of predicting acute ventilation changes from exposure to carbon monoxide in both man and animals. This Dynamic Physiological Model (DPM) is based on previously published work, reformulated, extended, and combined into a single model. Model parameters are determined from literature values, fitted to experimental data, or allometrically scaled between species. The model predictions are compared to ventilation-time history data collected in goats exposed to carbon monoxide, with quantitatively good agreement. The model reaffirms the role of brain hypoxia on hyperventilation during carbon monoxide exposures. Improvement in the estimation of total ventilation, through a more complete knowledge of ventilation control mechanisms and validated by animal data, will increase the accuracy of inhalation toxicology estimates.

The DPM provides a quantitative explanation of the hyperventilation and subsequent ventilation depression associated with acute carbon monoxide inhalation. The build up of carboxyhemoglobin and corresponding reduction in oxygen delivery to the brain leads to anaerobic glycolysis and the observed lactate generation. Using buffering relations, the acidity changes are reproduced and those changes, thorough the modified Duffin's model, generates the observed hyperventilation. The continued reduced oxygen delivery leads to a decrease of central chemoreceptor response and the observed ventilation depression. The validity of this physiologically based explanation of carbon monoxide induced hyperventilation is further supported by the agreement with other measured blood gas quantities.

The DPM also provides a rational basis for extrapolation between species. While exercise and sleep apnea studies can be made with human subjects, knowledge of immediate incapacitation and delayed lethality from inhaled gases must come from animal testing. A physiologically based ventilation response model allows the concepts developed for man to be used to interpret animal tests and extrapolate those results accurately into human internal dose estimates.

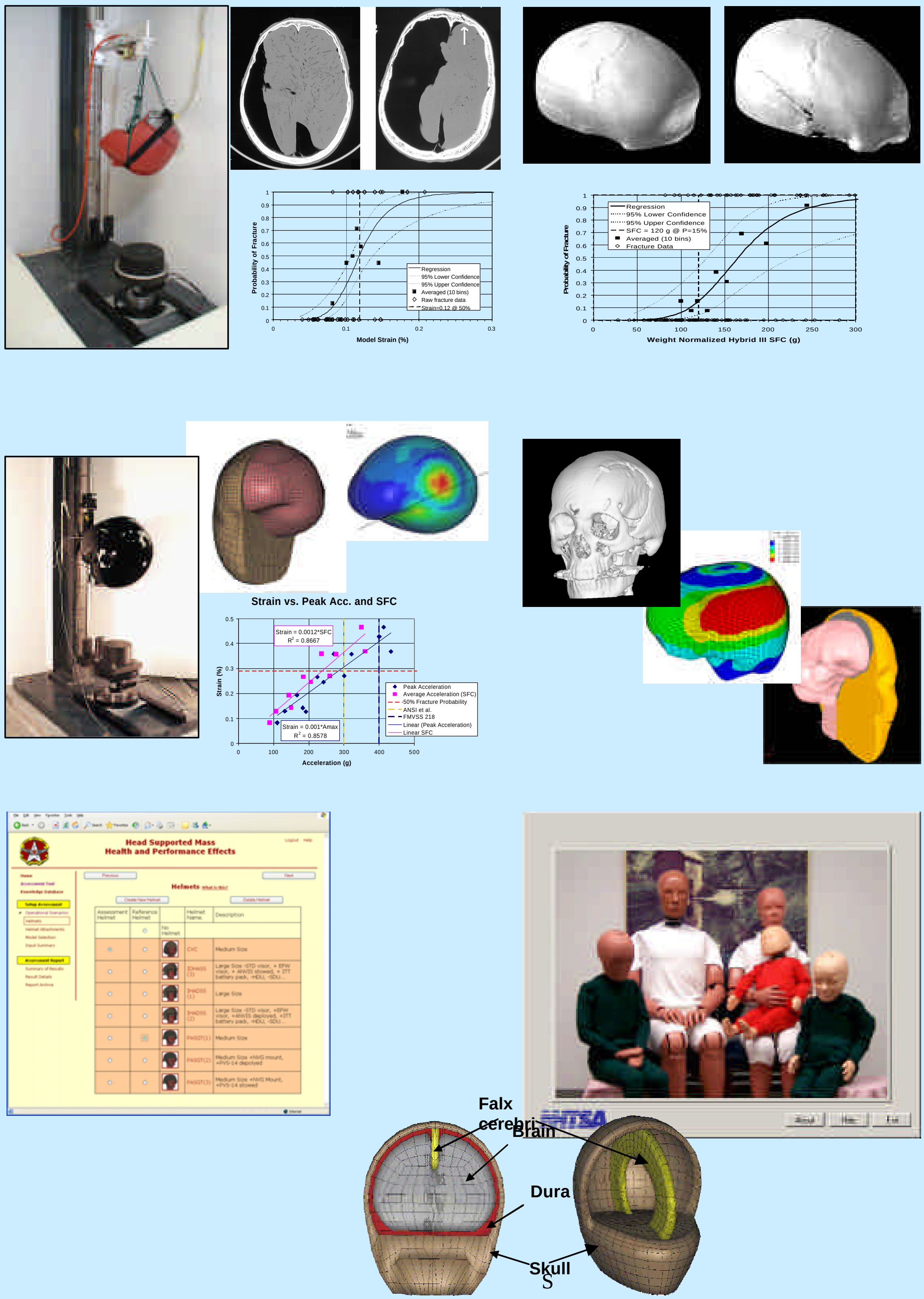
There are many areas of uncertainty in the modeling of ventilation control, including the exact mechanism by which oxygen alters the peripheral chemoreceptor response and the details of how the central chemoreceptor senses and responses to the humoral properties. Further testing and theoretical investigations are warranted. A phenomenological model allows the possibility of using animal tests to explore these and other breathing control issues in a safer and more invasive manner than would be possible with human subjects.

The DPM model extends previous models that address hypoxic and hypercapnia environments to include carbon monoxide. These three gasses occur universally in fire environments and each significantly alters ventilation and, consequently, the uptake of all of the noxious gases. The extended model will allow better estimates of internal dose, thus improving the prediction of immediate incapacitation and delayed lung injury.



Dynamic Physiology Model Schema

5. Head and Neck Injury Research



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HEAD SUPPORTED MASS: HEALTH AND PERFORMANCE EFFECTS

Significance

The customer has a single application to assess the effects of a head supported mass (HSM) on the health and performance of a soldier and to access research documents related to HSMs

Application framework allows for the inclusion of future models, criteria, and research documents

Product

--Head Supported Mass: Health and Performance Effects, Amankwah, K., Shen, W., and Zhang, J., http://216.55.162.19/HSM/, November 2005.

--Web-based application for Assessing Human Effects of Head Supported Masses, Amankwah, K., Shen, W., and Zhang, J., J3150-06-286, February 2006.

--An Application for Head Supported Mass Assessment, Amankwah, K., Shen, W., Zhang, J., and Stuhmiller, J., presented to CHPPM, October, 2005.

--An Internet Application for the Assessment of HSM Effects, Alem, N., Amankwah, K., Zhang, J., Shen, W., Chancey, V.C., AsMA 77th Annual Scientific Meeting, May 2006.

Purpose: A current trend in the military has been to add more helmet-mounted equipment, providing soldiers with the information and protection they require on the battlefield. However, the increase in the amount of head supported mass (HSM) may cause decrements in performance or increases in neck injury risk. The United States Army Aeromedical Research Laboratory (USAARL) has led extensive research into this area and needed to integrate their findings into a product.

Challenge: Combine the HSM research results into a product for determining the risk of neck injury due to different HSMs under various operational scenarios

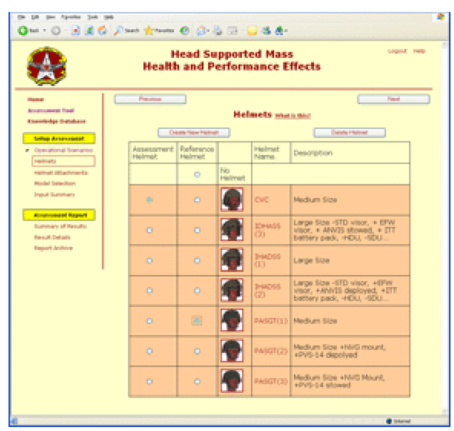
Solution: We integrated the available neck injury models and criteria into an internet based application that assessed the risk of neck injury due to HSMs

Application Features:

- Neck injuries and performance calculations due to soldier demographics, helmet system properties, and operational scenario characteristics
- Selection of injury models and criteria to utilize during assessment
- User customizable helmets, attachments, and operational scenarios
- Compare two helmet systems
- Assessment report that includes risk boundaries and caveats for the results
- A knowledge database that stores USAARL documents related to HSM research
- Interface that guides user step-by-step through the assessment

Customer Benefits:

- HSM injury models and criteria integrated into a single application
- Single location to assess HSMs and access research documents
- Internet based application accessible anywhere an internet connection is available
- No software installation or software updating required
- Application framework allows for the inclusion of future models, criteria, and research documents



Web page from HSM application showing library of helmet systems available for the user to assess.

CORRELATES TO TRAUMATIC BRAIN INJURY

Significance

It is shown that the most important risk factors to impact-induced concussion are the peak rotational acceleration and the cumulative number of impacts.

Product

--Correlates to Traumatic Brain Injury in Non-human Primates, M. Vander Vorst, K. Ono, P. Chan and J. Stuhmiller, Journal of Trauma, 2006 (in press).

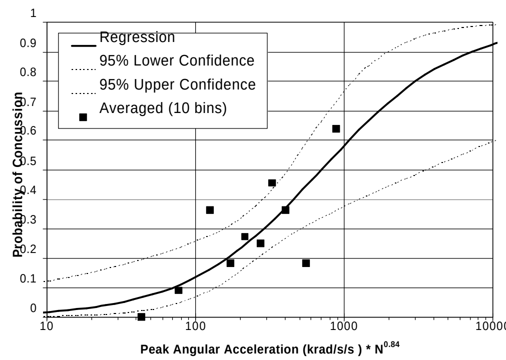
Traumatic brain injury (TBI) is a major health problem, both in terms of the economic cost to society and survivor's quality of life. To develop devices to protect against TBI requires a criteria which relates observed injury to measurements of head kinematics. The objective of this work is to find the best statistical correlates to impact-induced TBI using a self-consistent set of historical data from impact tests on non-human primates.

A database was constructed and qualified from historical head impact tests on nonhuman primates. Multivariate logistic regression analysis with backwards stepwise elimination was performed. Variables considered are the peak rotational acceleration, Ω_{max}; the peak linear acceleration, A_{max}; and the number of impacts, N.

Bivariate combinations of angular acceleration and the number of impacts are the best correlates to all modes of TBI considered, i.e., concussion, subarachnoid hemorrhage (SAH), brain contusion, and subdural hematoma (SDH). For a non-human primate with 100 gram brain mass, the criteria that the probability of TBI is less than 10% by injury mode are:

Injury	Correlate	Japanese Monkey (krad/s/s)	Man (krad/s/s)
Concussion	$\Omega_{max}N^{0.84}$	< 69	<13
SAH	$\Omega_{max}N^{0.70}$	< 160	<30
Contusion	$\Omega_{max}N^{0.35}$	< 160	<30
SDH	$\Omega_{max}N^{0.60}$	< 280	<53

TBI prevention criteria based on 10% probability of injury to Japanese monkey and scaled to man



The bivariate quantity, $W_{max}N^{0.84}$, combining peak angular acceleration with the number of impacts is the best correlate to concussion, statistically validating the cumulative effects of repeated impacts.

Cited References

Human head tolerance to sagittal impact reliable estimation deduced from experimental head injury using subhuman primates, K. Ono et al., *Proceedings of the 24th Stapp Car Crash Conference*, 1980.

Human Head Tolerance to Lateral Impact Reduced from Experimental Head Injuries Using Primates, A. Kikuchi et al., *Proceedings of the Ninth International Technical Conference on Experimental Safety Vehicles.* 1982.

Statistically and Biomechanically Based Criterion for Impact-Induced Skull Fracture

Significance

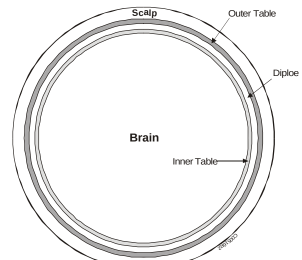
A biomechanically based, statistically significant criterion for impact-induced linear frontal skull fracture was developed. This criterion limits a particular averaged acceleration of a Hybrid III crash test dummy.

Product

--An imaging-based computational and experimental study of head injury I: Skull fracture model, Bandak, F, Vander Vorst, M, et al., J. Neurotrauma, 1995.

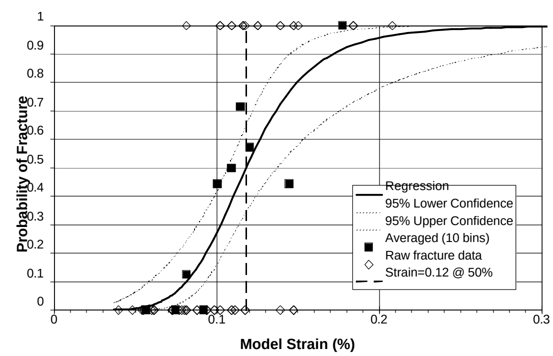
--Automated Finite Element Modeling of the Skull: Box-head Users Guide, Vander Vorst, Michael J., Technical Note J2997.103-02-171, Mar.2, 2002.

Hybrid III headform on drop assembly with target

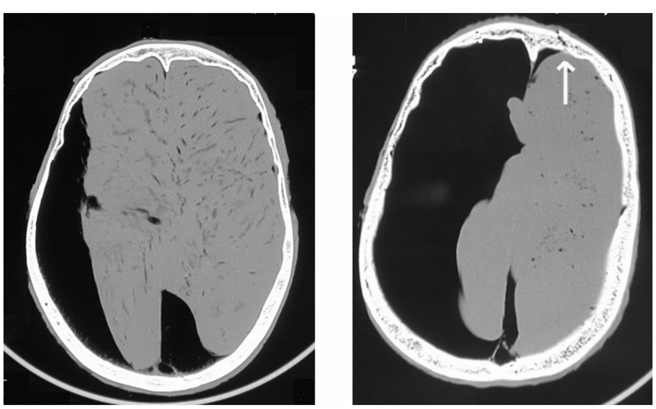


Three-dimensional spherical head model

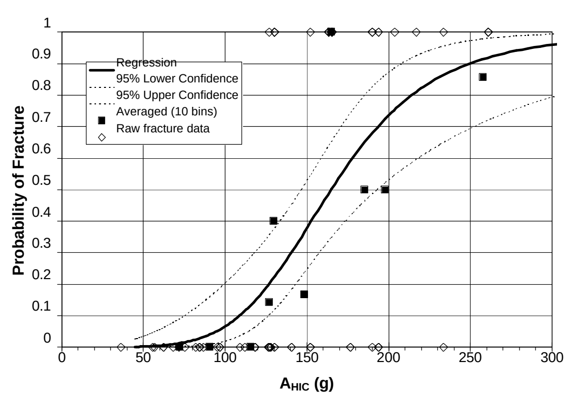
This work developed a skull fracture criterion for impact-induced head injury, using post mortem human subject tests, anatomical test device measurements, statistical analyses, and finite element modeling. It is shown that skull fracture correlates with the tensile strain in the outer table of the cranial bone, and an index termed the Skull Fracture Correlate (SFC) predicts injury. SFC offers several advantages as a protection criterion. It accounts for compliance of the impact site; it is extensible to varying head mass; and it is easily implemented using current software. For a 15% or less probability of skull fracture the criterion is SFC $<$ 120 g, with a 95% confidence band of 88 $<$ SFC $<$ 135 g.



Correlation of strain to skull fracture



Pre- and post-test CT images showing fracture



Correlation of AHIC (SFC) to Skull Fracture

communications

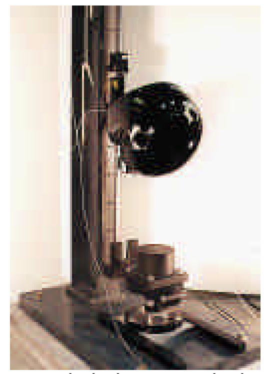
BIOFIDELITY OF MOTORCYCLE HELMET CRITERIA

Significance

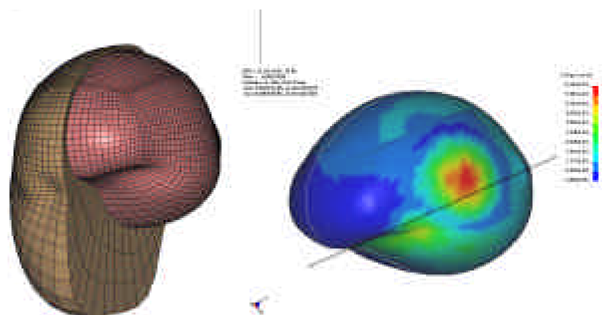
It is demonstrated that peak acceleration and SFC are biofidelic risk factors to impact skull fracture for motorcycle helmet safety criteria.

Product

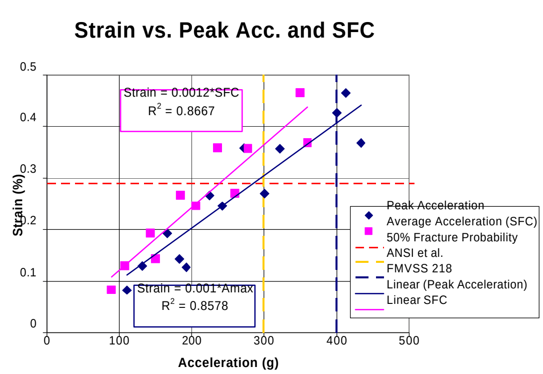
--Biofidelity of Motorcycle Helmet Criteria, M.J. Vander Vorst and P.C Chan, Proceedings of the Thirty-Third International Workshop on Injury Biomechanics Research, 2006.



Motorcycle helmet test device



Strain computed using anatomically-based FEM



Peak acceleration and SFC are both good correlates to computed strain

To protect motorcyclists in accidents, Section 218 of the Federal Motor Vehicle Safety Standards (FMVSS) sets criteria for motorcycle helmets based on the magnitude and duration of the acceleration of a vertically guided helmeted headform at impact. Worldwide, there are several other helmet standards. For example, the Economic Commission for Europe standard, ECE 22.4, limits both the Head Injury Criterion (HIC) and peak acceleration computed from a free falling helmeted headform; while the ANSI and Snell Memorial Foundation standards limit only the peak acceleration. Previous work established that the mechanical strain predicted by an anatomically based finite element model is a good biomechanical correlate to bare-headed, impact-induced, linear skull fracture. This effort determined that peak acceleration and SFC (the average acceleration over the HIC time interval) are biofidelic criteria to impact skull fracture for motorcycle helmets, using computed strain as the biomechanical basis for biofidelity.

5.1.1 Cited Reference

Vander Vorst, M, Chan, P, et al., (2004). A New Biomechanically-based Criterion for Lateral Skull Fracture, Annual Proc Assoc Adv Automotive Med, 48.

BIOMECHANICALLY-BASED CRITERION FOR IMPACT-INDUCED LATERAL SKULL FRACTURE

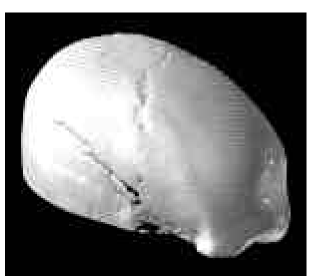
Significance

SFC, the Skull Fracture Criteria, is a biofidelic risk factor for both side and frontal-impact induced skull fracture.

Product

--A New Biomechanically-based Criterion for Lateral Skull Fracture, Vander Vorst, M.,P. Chan, et al., Annual Proc Assoc Adv Automotive Med 48: 181-95, 2004.

This work developed a skull fracture criterion for lateral impact-induced skull fracture using postmortem human subject tests, anatomical test device measurements, statistical analyses, and finite element modeling. It was shown that skull fracture correlates with the tensile strain in the compact tables of the cranial bone as calculated by the finite element model and that the Skull Fracture Correlate (SFC), the average acceleration over the HIC time interval, is the best predictor of skull fracture. For 15% or less probability of skull fracture the lateral skull fracture criterion is SFC < 120 g, which is the same as the frontal criterion derived earlier. The biomechanical basis of SFC is established by its correlation with strain.

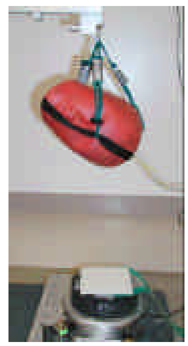


(a) Pretest Scan *(b) Posttest Fracture*

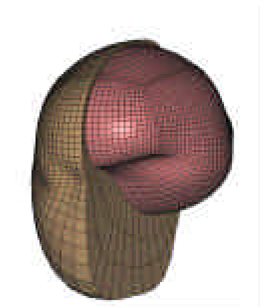
Three-Dimensional Reconstruction of Pretest and Posttest CT Scans

Cited References

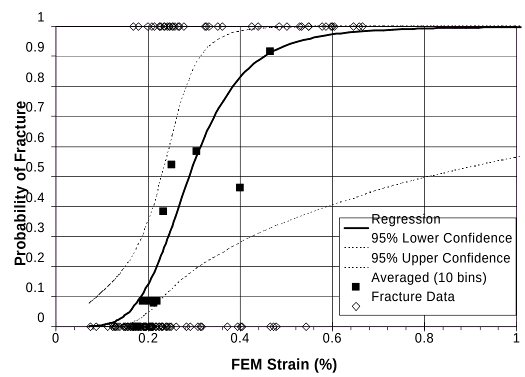
Vander Vorst, M., Stuhmiller, J., et al., (2003). Biomechanically-based Criterion for Impact-Induced Skull Fracture, Annual Proc Assoc Adv Automotive Med.



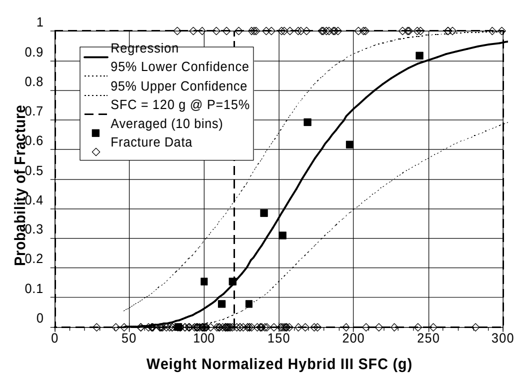
Hybrid III Drop Test



Anatomical head model



Logistic regression of calculated strain to skull fracture



Logistic regression of SFC to skull fracture

AUTOMATED FINITE ELEMENT MODELING OF SKULL

Significance

Software was developed to generate an anthropomorphically correct, three-dimensional, finite element model of the human head from a medical image. The use of this model will lead to biomechanically based correlates to head injury.

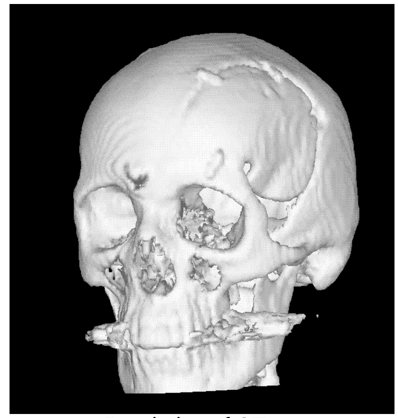
Product

--An imaging-based computational and experimental study of head injury I: Skull fracture model, Bandak, F, Vander Vorst, M, et al., J. Neurotrauma, 1995.

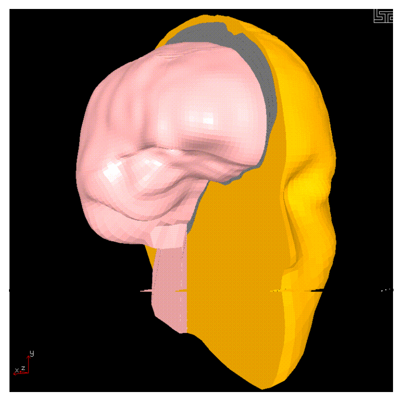
An automated procedure of generating an in vivo, patient specific, three-dimensional finite element model of the head from a computed tomographic (CT) scan is developed. Three-dimensional finite element stress/ strain analysis of the human head during impact provides an understanding of head impact injury. This automated procedure segments the head into cranial bone, facial and bone containing the brain and models this bone as variable thickness shell elements. The face and scalp are modeled using hexahedral elements which extend from and conform to the cranial shell elements. An elliptic equation is solved to discretize the brain volume into hexahedrons which also conform to the cranial shell. CT values determine the inhomogenous material properties. Results are presented of a vertical impact of the skull cap onto a hard surface at 37 miles per hour.

Cited References:

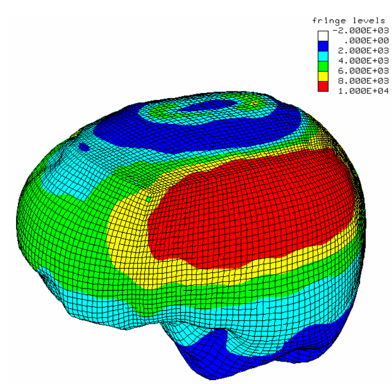
Hodgson, Voigt R., and Thomas, L. Murray. (1973). Breaking Strength of the Human Skull vs. Impact Surface Curvature, Final Report DOT HS-801 002, November 1973.



Rendering of CT scan



Rendering of finite element mesh computed from CT image.



Stress distribution on outer table of skull due to impact

communications

SIMon Computer Code

Significance

Provide support of code development, future releases, and maintenance of the SIMon computer code, a valuable tool for evaluating the extent of and possible means of prevention of injuries sustained in automobile accidents.

Product

--SIMon User's Manual, Masiello, Paul J., User's Manual J2997.104-01-160, Nov. 2001.

--SIMon Simulated Injury Monitor Version 3.0 Computer Code, Masiello, Paul J., October 26, 2003. Released and distributed at 2003 Annual Stapp Conference, San Diego, California.

--SIMon: A Simulated Injury Monitor; Application to Head Injury Assessment, Bandak, F.A., Zhang A.X., Tannous, R.E., DiMasi, F., Masiello, P. and Eppinger, R., 17th International, Technical Conference on the Enhanced Safety of Vehicles (ESV), Amsterdam, Netherlands, June 4-7, 2001.

--Implementation of Euler Angles in the NAP Computational Model, Kan, K.K. and Masiello, P.J., Report J2997.104-02-169, February 2002.

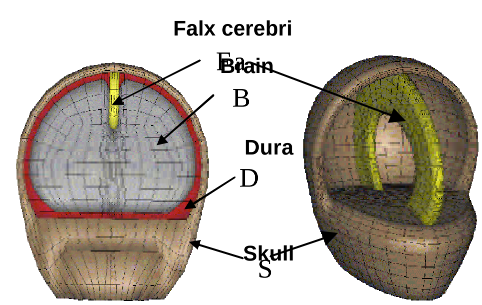
--Qualification of the NAP Computational Model, Rev. 1, Kan, Kit K. and Masiello, Paul J., Report J2997.53-02-140, Feb. 2002.

--NAPDA Software, Ver. 5.1, Masiello, Paul J., April 2001.

--NAP Data Analyzer Software, Ver. 1.0, Dec. 2000

The SIMon (*Simulated Injury Monitor*) computer code is a next generation tool for the assessment of bodily injury resulting from automobile collisions. It was developed by Jaycor/Titan, now a part of L-3 Communications, under NHTSA sponsorship. The objective of SIMon is to provide an integrated and simple-to-use mechanism to utilize recent advancements in computational techniques that can be employed to simulate human injury response. In light of recent advances in computer hardware, the idea of detailed injury assessment in real-time can be brought much closer to reality. SIMon provides a convenient interface between a user and biomechanics related test data of interest, allowing invocation of a detailed mathematical model for simulation of impact injury to a specified body region. Presently, the focus of SIMon is on head injury, but other models addressing the neck, thorax and lower extremities are planned for the future.

At present, the most useful feature of SIMon is a model to process Nine Accelerometer Package (NAP) test data, as well as data recorded by angular velocity (AV) sensing devices (e.g., MHD sensors). NAP devices allow measurement of nine linear accelerations along three orthogonal directions, for the purpose of computing accurate and reliable values for rotational velocities and accelerations. These quantities play a pivotal role in the assessment of head injury. In the case of AV sensing devices, the angular velocity is measured directly, but rotational acceleration is still desired, as well as transformation from body-fixed coordinates to an inertial frame of reference. The resulting linear and rotational angular velocities constitute data for the construction of suitable load curves for a finite element model (FEM) of the human brain. This model can be invoked by SIMon, and the progress of the FE calculation, as well as graphical results, can be displayed by SIMon in real-time.



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SIMon is designed to access a database either supplied by NHTSA or constructed and maintained by a user with the help of SIMon dialogs. Familiarity with database tools or software is not required. The user can easily add a test to the database by a simple drag/drop operation, referencing data files from the Windows Explorer. Content of database fields of interest (such as the test number, date, test performer, etc.) can be entered directly from within SIMon dialogs. Once added, a test can be deleted from the database, or its database fields can be edited. Assembly and maintenance of the user database is managed entirely by SIMon.

Injury assessment is accomplished by viewing the graphical and printed data generated by SIMon for the particular model invoked. Individual plots can be generated in their own window and saved permanently.

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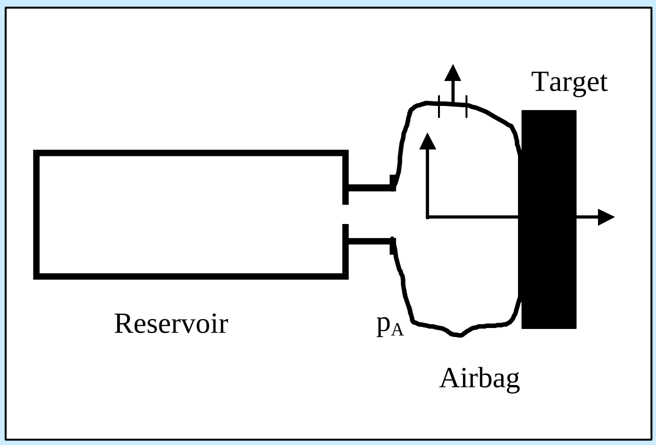
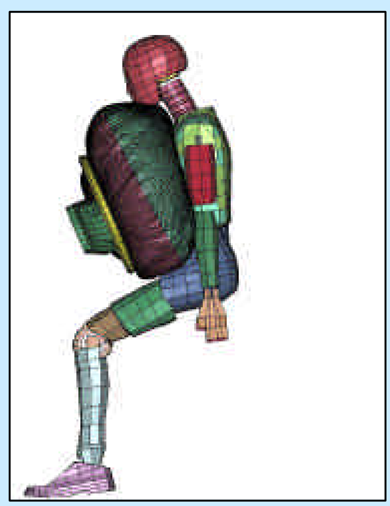
6. Distributed Thoracic Trauma Research





AIRBAG TEST SYSTEM (ATS)

Significance

An Airbag Test System (ATS) was developed and constructed to provide a method to conduct laboratory airbag tests. The ATS is an efficient research tool to carry out controllable and repeatable deployment tests to study airbag-dummy interaction and inflation characteristics.

Product

–An Experimental Air Bag Test System for the Study of Air Bag Deployment Loads, Bandak, F., Chan, P. C., Ho, K. H., and Lu, Z., Int. J. Crashworthiness, 7(2), pp.1-12, 2002.

--Airbag Test Simulator (ATS) Calibration and Parametric Studies Using Simple Targets, Lu, Z. and Chan, P. C. Jaycor Report J2997.102-03-189, Contract No. DAMD17-96-C-6007, January 2003.

--Evaluation of Hybrid-III and THOR Dummy Head/neck Responses to Airbag Load at Close Proximity, Chan, P. C. and Lu, Z., 2003 IRCOBI Conference, Lisbon, 2003.

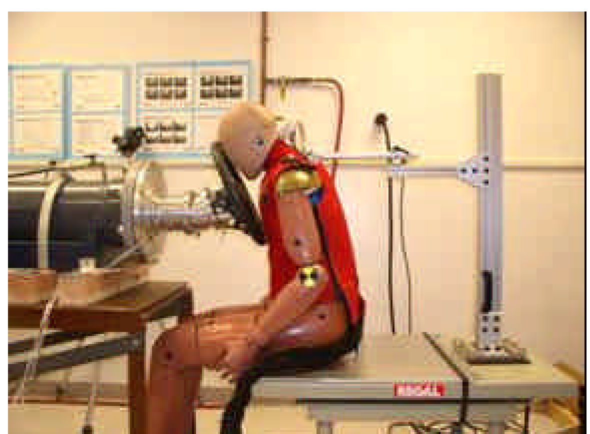
--Laboratory Study of Hybrid-III and THOR Dummy Head/neck Responses to Airbag Load at Close Proximity, Chan, P. C. and Lu, Z., SAE Paper 2004-01-0320, 2004.

--Out-of-Position Airbag Load Sensitivity Study, Lu, Z. and Chan, P. C., SAE 2004 Transactions Journal of Passenger Cars: Mechanical Systems, 2004-01-0847, pp. 507-520, 2004.

A pneumatic-driven airbag test device, the Airbag Test System (ATS), has been constructed to conduct repeatable laboratory tests of airbag-dummy interaction. The ATS uses a cylindrical reservoir pressurized by laboratory air as the energy source to simulate the pyrotechnic inflator. The pressurized reservoir connects to the airbag module through an orifice. An aluminum diaphragm is used to hold the pressurized gas initially from discharging. Deployment is initiated by rupturing the diaphragm allowing the gas to discharge and inflate the bag from the center of the steering wheel.

The ATS has been calibrated to replicate selected fleet airbag inflations. The pneumatically driven ATS was demonstrated to be a highly useful and efficient apparatus for studying airbag loads and airbag-dummy interaction. The significance of using the ATS is that repeatable tests can be carried out with accurately controlled inflation without using the fleet inflators. This ability to generate repeatable data is important since it is well known that airbag tests tend to produce data variability (Melvin, et al., 1993), making it difficult to conclude phenomenological observations.

The ATS has been used to study the head/neck response of the advanced anthropomorphic test dummy, THOR, developed by NHTSA. The THOR responses were compared against those of the Hybrid-III dummy. ATS results show that THOR can distinguish load at the occipital condyle (OC) from the total load across the entire upper head/neck cross section and there are significant differences in terms of head/neck responses between the THOR and Hybrid III dummies. Sensitivity study conducted using the ATS confirmed the sensitivity of airbag loads to the variations of test conditions, including dummy configuration, airbag cover,



THOR dummy seating in front of ATS

steering wheel, bag folding pattern, and the use of neck shield. The results identify a number of critical parameters that can significantly affect airbag-dummy interactions.

Cited References:

Melvin, J. W., Horsch, J. D., McCleary, J. D., Wideman, L. C., Jensen, J. L., and Wolanin M. J. (1993). "Assessment of air bag deployment loads with the small female Hybrid II dummy," in the 37th Stapp Car Crash Conference Proceedings, P-269 (SAE, 1993).

FE Modeling of Airbag-Dummy Interaction

Significance

Finite element airbag-dummy models have been constructed and validated against benchmark test data. The models capture the airbag inflation and loading phenomena with favorable data comparison. Simulation studies of the effects of standoff and crash speed have been carried out with reasonable results obtained.

Product

--Finite Element Simulation Study of Airbag Load Phenomena, Lu, Z. and Chan, P. C., SAE Paper 2005-01-030, 2005.

--Finite Element Model Simulation of Airbag-Dummy Interaction, Lu, Z. and Chan, P. C., Proceedings of the Thirty-Third International Workshop on Human Subjects for Biomechanics Research, Washington, DC, 2005.

Finite element (FE) airbag models have been developed to simulate the deployment process of the airbag with occupant interaction. Two fleet driver-side airbags, one from a minivan and the other from a mid-size sedan, were selected for the study. Using the LS-Ingrid software (1998), the folded airbag models were constructed from meshed geometry CAD files. The folds and rolls follow the physical bag. The dimensions of the folded bag are the same as the physical module. No shell intersection is allowed in the initial state of the folded bag.

The FE software used for this study was LS-DYNA, and the uniform pressure gas-flow option was selected. The airbag models were first validated against the Airbag Test System (ATS) data using free swinging cylindrical surrogate targets. Two cylindrical targets of different sizes were used in the ATS tests with the target standoff from the airbag varied over a range from in-position (IP) to out-of-position (OOP) proximities. The calculated bag pressures and target responses were shown to agree well with the data.

After validation of the airbag models, they were placed inside a chamber that is connected to spokes and the steering wheel to complete the airbag-steering wheel model. The airbag-steering wheel models were then placed in front of the dummy models at the ISO-2 OOP position. The deformable 5th and 50th Hybrid III models from LSTC were used in the simulation.

Using the airbag-dummy model, FE simulations have been performed to study airbag-dummy interactions with validation against ATS data using 5th and 50th Hybrid III dummies. The airbag unfolding process is well simulated by the model. Good data agreement is observed for airbag pressure and dummy accelerations, while qualitative data agreement is achieved for head/neck loads. Simulation results for the effects of standoff and crash speed on dummy responses are generally considered reasonable.

The present study shows a finite element airbag model with a uniform pressure method can give satisfactory level of validation to capture the key events of the airbag inflation and bag-dummy interaction. Detailed insights of bag-dummy interaction under various standoffs and crash conditions are also identified using model simulations.

Cited References:

LSTC (1998). "LS-INGRID 3.5 Graphical User Interface Manual," August 1998.

Crash simulation using the airbag-dummy model.

LUMPED-PARAMETER AIRBAG-TARGET MODEL

Significance

An analytical model was developed to simulate the airbag deployment with favorable validation against test data. The model captures the observed features of the bag pressures and target responses. The model has provided an in-depth phenomenological explanation of the proximity test data on the effects of inflation on the OOP and membrane load trend. The understanding of such a relationship is necessary to guide airbag research.

Product

–An Experimental Air Bag Test System for the Study of Air Bag Deployment Loads, Bandak, F., Chan, P. C., Ho, K. H., and Lu, Z., Int. J. Crashworthiness, 7(2), pp.1-12, 2002.

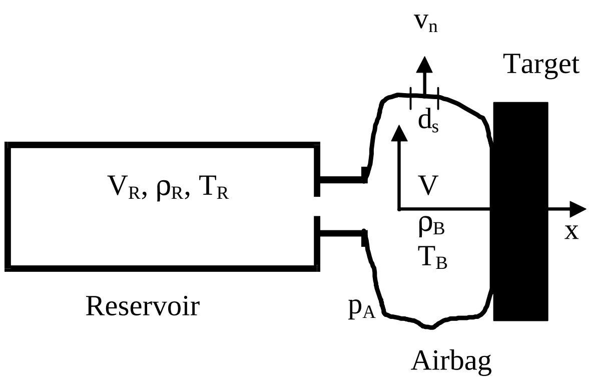
A lumped-parameter model was developed to describe the deployment process of the airbag and its interaction with a rigid target. The model follows an integral approach that treats the unfolding of the bag during deployment as a uniform thinning of the bag surface with specified volume-area functions. We assume the pressure in the bag to be uniform in space, but varying in time. A portion of the bag surface touches and moves with the target while the rest expands based on the bag pressure and membrane mass.

The model requires the specification of the total bag surface area and the bag-target contact area, which are computed as functions of the airbag volume and the target position. The volume-area functions are bounded by the initial and fully deployed characteristics of the airbag with parameters that can be varied to describe the intermediate unfolding process. The volume-area functions as modeled are semi-empirically based but they address perhaps the least known aspects of bag-target interaction with significant implications on loads delivered to occupants.

The model was validated against both the fleet inflator and Airbag Test System (ATS) test data, including the proximity tests to study standoff effects on target response. The recorded inflator tank pressure was used for the energy and mass inflow inputs to the model. The calculated tank pressure and temperature agree well with the data. The target velocity response was well reproduced by the model. For the ATS tests, the calculated reservoir and bag pressures agree with the data. The calculated target acceleration also compares favorably with the data. These favorable data comparisons validate the inflator model, gas dynamics, and flow coefficients used in the model.

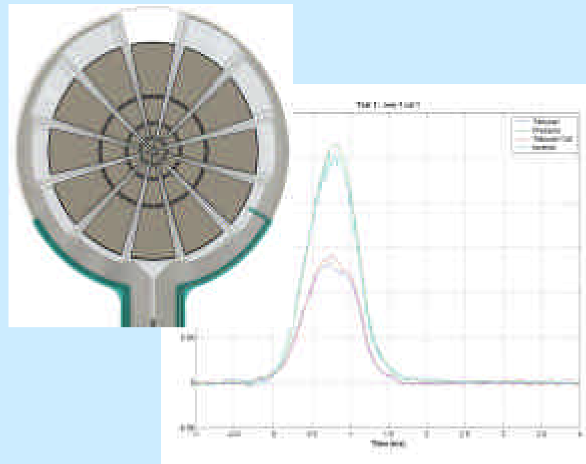
Model simulations have helped explain the proximity test results that cannot be easily obtained just from the test data. It is shown that target velocity (and load) decreases with standoff due to the reduction of early inflation pressure pulse, extension of the intermediate expansion, and the slowing down of the final membrane load.

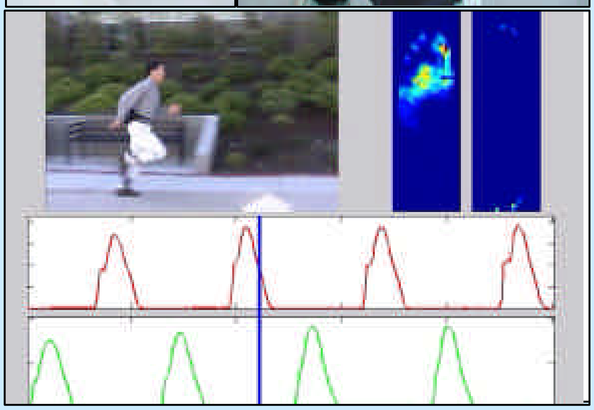
Model results have also provided insights in the effects of inflation energy and mass flow on target response. The model results show that only a very small fraction, like 3%, of the total energy is delivered to a target, while 60% is stored inside the bag. For a sealed bag, the target response is independent of inflator temperature if the total energy is held constant. Venting reduces the target load primarily during the final pressurization (membrane) phase. For a vented bag, the target velocity decreases with higher inflator temperature.

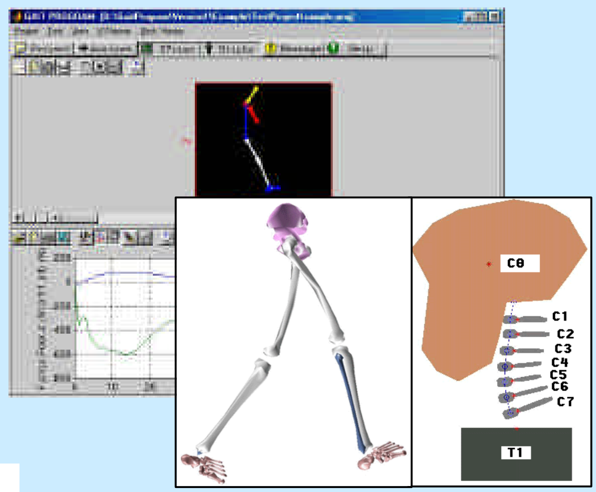


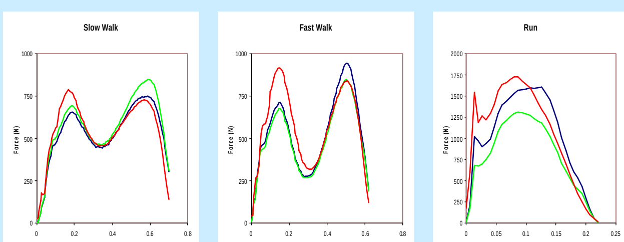
ATS reservoir, airbag, and target model

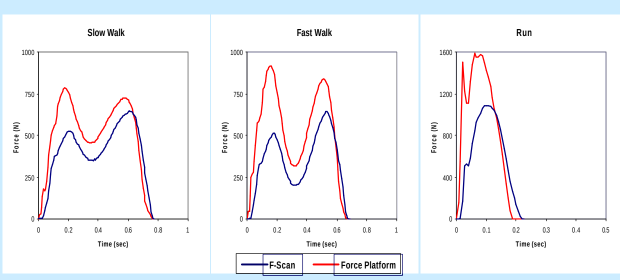
7. Biomechanics Research

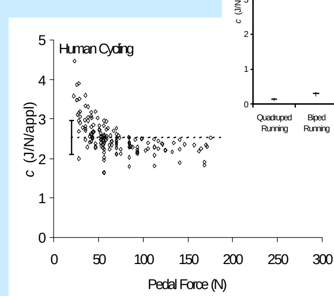


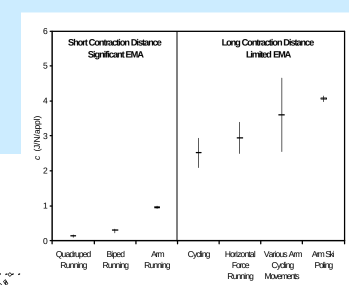












BIOMECHANICAL MODELING TOOLBOX

Significance

A general toolbox consists of kinematics, inverse and forward dynamics algorithms, data conversion routines, graphical algorithms, and many utility routines for mathematical calculation and file operation was developed. It can be used to develop both inverse and forward biomechanical models. One sample application using the toolbox is a customized gait analysis program developed from USARIEM, Gait3D

Product

--Articulated Human Biomechanical Modeling Toolbox, Part I: Overview, Rigid Body Formulations, and Examples, Shen, W., Report J3150.31-00-135, Dec. 2000.

--Articulated Human Biomechanical Modeling Toolbox, Part II: Toolbox Routines, Shen, W., Report J3150.31-00-136, Dec. 2000.

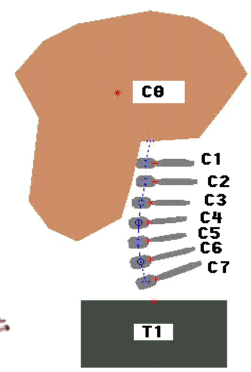
--Gait 3D User's Manual, Ver. 1.0, Shen, W., Report J3150.31-00-134, Dec. 2000

This effort attempted to develop an articulated human biomechanical modeling toolbox. Efforts were made to review the current status of modeling techniques and to develop rigid body formulations suitable for human biomechanical modeling. The developed toolbox consists of kinematics, inverse and forward dynamics algorithms, data conversion routines, graphical algorithms, and many utility routines for mathematical calculation and file operation. Both inverse and forward sample models, such as a 3D lower extremity model, a 3D whole body human model, and a human head-neck model, were developed.

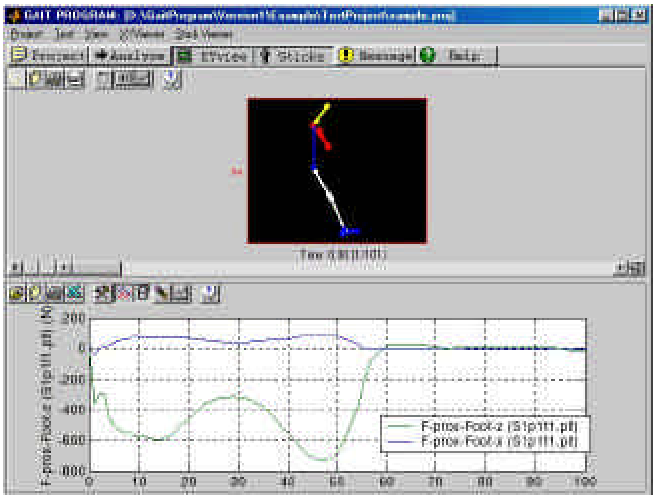
The following specific tasks were conducted

- Review of current techniques for human biomechanical modeling
- Developing three-dimensional kinematics algorithms
- Developing forward dynamics formulations for multibody constrained systems
- Developing commonly used algorithms related to inverse dynamics analysis
- Developing data structure and data conversion routines
- Developing some graphical algorithms for visualizing data and model
- Developing utility routines for mathematical calculation and file operation
- Developing example problems for both inverse and forward dynamics analysis

The toolbox was also used to upgrade gait analysis software for USARIEM, Gait3D. Gait3D supports the test setup of USARIEM motion analysis system with one force plate and fourteen markers. It



allows running, visualizing and analyzing multiple gait tests in a simple graphical layout. It uses the inverse dynamics and graphical routines developed by Shen and Stuhmiller and can be customized for various test setups.



Ongoing efforts are focusing on reviewing and developing muscle models. This will expand the toolbox's capabilities to handle human biomechanical modeling where muscle activities have to be accounted for. Specific applications may include solving muscle load sharing in inverse dynamics analysis and understanding overuse injuries related to muscle activities.

PORTABLE F-SCAN SYSTEM

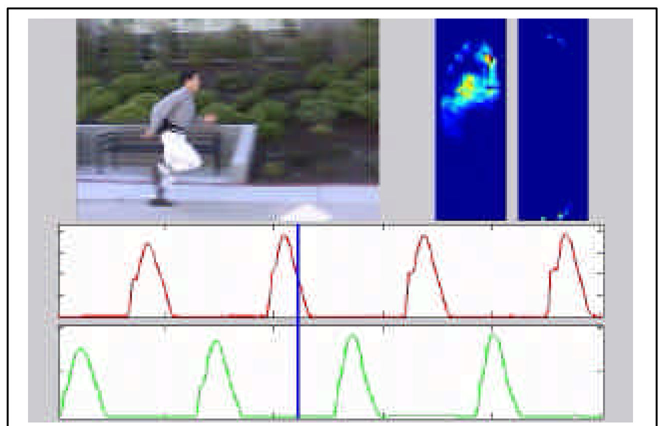
Significance

The portable F-scan system was developed to collect plantar pressure data from a set of conditions that are not typically analyzed using traditional biomechanical methods, allowing an analysis under different terrains and gait speeds. Such information may be valuable for many studies, including overuse injuries.

Product

—Application of a Portable F-scan System, Sih, Bryant L., Report J3150.32-01-145, July 2001.

The portable F-scan System is comprised of foot sensors and a data storage pack.



The setup allows the collection of plantar pressure data in nonlaboratory conditions.

The F-scan system (Tekscan, Inc., Boston, MA) is an in-shoe sensor that measures plantar pressure distribution using a thin disposable sheet composed of an array of pressure sensing elements or sensels. Currently, the F-scan system is “tethered” to a PC-compatible computer with 10-meter cables. The portable system developed by Jaycor, Inc. is designed to temporarily store F-scan sensor output in a transportable memory system, which can be downloaded to a computer at a later time. The current prototype can collect 4000 frames of data from each foot.

To demonstrate the capabilities of the portable system, plantar pressure data was collected from a subject performing a variety of movements that would have been impractical or impossible to measure using a nonportable system. In addition, a few analyses were completed to show the range of information available from the system. Specifically, walking and running was recorded outside on different terrains. These included level ground, both up and down a slope and on stairs. Step rate, stance time, total load and loads on different regions of the foot were calculated from the data. Significant differences were seen in the measurements depending on the terrain.

IMPROVING F-SCAN ACCURACY

Significance

The accuracy of the F-scan system is compromised by its viscoelastic behavior, causing errors during calibration and data collection. Applying a properly calibrated standard linear solid model to the F-scan output substantially reduces the error.

Product

—Improving Accuracy of the F-Scan Sensor, Sih, Bryant L., Report J3150.32-01-143, June 2001.

The F-scan system (Tekscan, Inc., Boston, MA) is a small in-shoe sensor that measures plantar pressure distribution using a thin disposable sheet composed of an array of pressure sensing elements or sensels. Previous studies have found that while the F-scan system is capable of accurately recording relative pressures, errors up to 62% in total load are possible (Luo et al. 1998; Sumiya et al. 1998).

The sources of error were investigated by analyzing the currently prescribed calibration method, characterizing the sensor both in and out of a shoe, and studying the long-term durability of the sensor. Because the sensor exhibits viscoelastic properties, part of the analysis involved fitting a standard linear solid (SLS) model to the results. It is believed that this is the first time the F-scan system has been modeled as a viscoelastic material.

The creep-like behavior of loaded sensels caused calibration errors that contributed to total load errors exceeding 30% during walking and running trials. However, sensor output was consistent from trial to trial. Using a set of coefficients derived from an in-shoe sensor under a wide range of gait speeds resulted in an SLS model that can reasonably approximate the plantar forces from an F-scan sensor output. Compared to Tekscan's prescribed calibration method, mean error was reduced from 31% to 11% using the SLS model.

Sensor longevity was also investigated and the results suggest that overuse causes the gap between the two load-bearing surfaces of a sensel to collapse. The amount of time before the sensor becomes dysfunctional varies from sensor to sensor but it may be possible to develop models and criteria to account for the changes in the sensor before breakdown.

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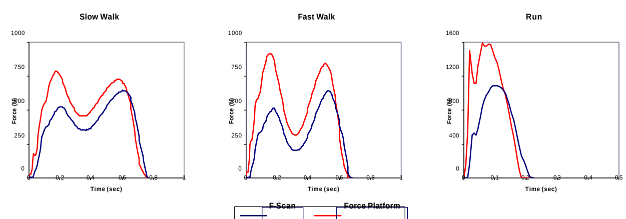
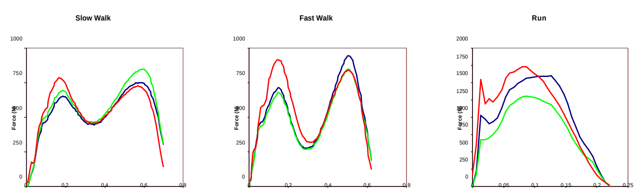


There are substantial differences in force values between the F-scan and the "gold-standard" force platform.



Both a linear spring (green) and SLS (blue) model decrease the error in the F-scan output.

THE METABOLIC COST OF FORCE GENERATION

Significance

Based on a review of existing data, a general relationship between metabolic cost and force generated is derived. There are other factors that can affect metabolic cost, including muscle contraction type, length and speed as well as fiber type and moment arm distances. Despite these confounding factors, an empirical relationship is derived that transcend species and movements.

Product

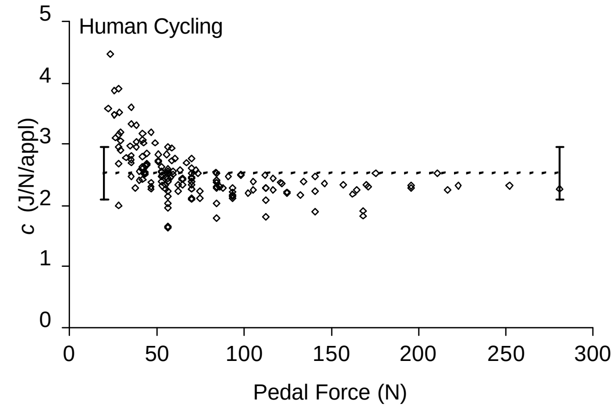
—The Metabolic Cost of Force Generation, Sih, Bryant L. and Stuhmiller, James H., Med. Sci. Sports Exerc., 35(4): 623-629, 2003.

We revisit the various equations that have been proposed to relate metabolic rate with mass, velocity and step contact time during running and find that metabolic rate is proportional to the external force generated and the number of steps per unit time. This relationship is in agreement with a previously proposed hypothesis that the metabolic cost to generate a single application of a unit external force is a constant.

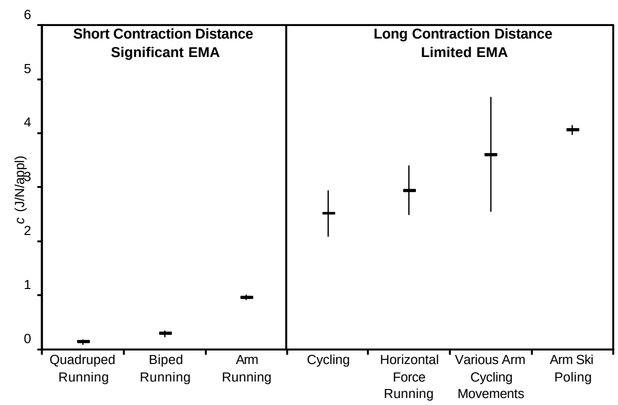
Data from the literature are collected for a number of different activities and species to support the hypothesis. Running quadrupedal and bipedal species, as well as human cycling, cross-country skiing, running (forwards, backwards, on an incline, and against a horizontal force), and arm activities (running, cycling, and ski poling), all have a constant metabolic cost per unit external force per application.

$$\dot{E} = c \cdot \bar{F} \cdot \dot{N}$$

The proportionality constant varies with activity, possibly reflecting differences in the aspects of muscular contraction, fiber types, or mechanical advantage in each activity. It is speculated that a more general relation could be obtained if biomechanical analyses to account for other factors, such as contraction length, were included.



The metabolic cost coefficient for cycling at various pedal forces and cadences. Ignoring low pedal forces (< 20 N) where the metabolic cost of overcoming limb inertia may have been influencing the results, the cost coefficient remained nearly constant over an almost 14-fold increase in pedal force and four-fold increase in pedal rate.



The mean value for the cost coefficients for seven movements. The proportionality constant varies with activity but remains constant for a given activity. Error bars represent one standard deviation.

BULL'S-EYE PRESSURE SENSORS

Significance ▸▸

A new pressure sensor, the Bulls Eye Tekscan sensor, was developed to measure the transient pressure distribution during impact tests.

Product ▸▸

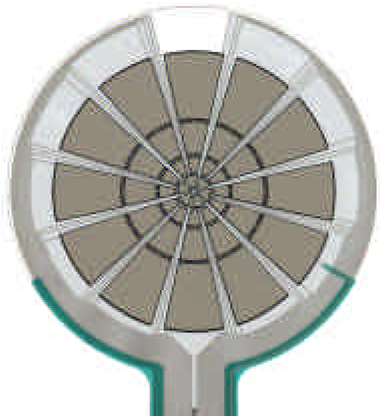
--Bulls Eye Tekscan Sensor, Vander Vorst, M.J., April 2003.

--Dynamic calibration test device for Bulls Eye sensor, Vander Vorst, M.J., May 2003.

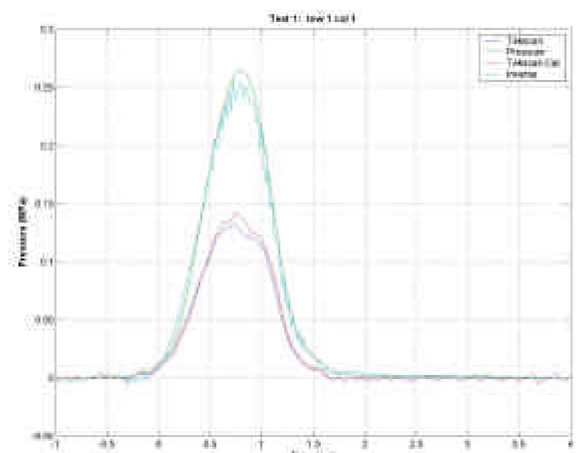
--Calibration and Interpretation of Tekscan Sensors, Vander Vorst, M.J., Report J2997.103-02-184, 2002.

--TekScan2Jif and Tscalibrate computer programs, Vander Vorst, M.J. and Long, D.W., Jan. 2002.

A new Tekscan pressure sensor, the Bulls Eye sensor, was developed for use in impact tests. This sensor has four concentric rings of cells with small cells in the interior rings to resolve the high pressures at the point of impact and larger cells in the exterior rings where the pressure is lower. TekScan instrumentation measures the transient pressure distribution at a sample rate of up to 10,000 Hertz over 42 cells. Calibration of TekScan sensors using TekScan's static methodology produced total forces, as measured by TekScan, that were far different from those measured by a force gauge. A test device and associated software was developed to calibrate each sensing element under a dynamic load. Using Jaycor's calibration method and data interpretation software, the TekScan instrumentation now measures dynamic pressure distributions during an impact that agree with force gauge measurements.

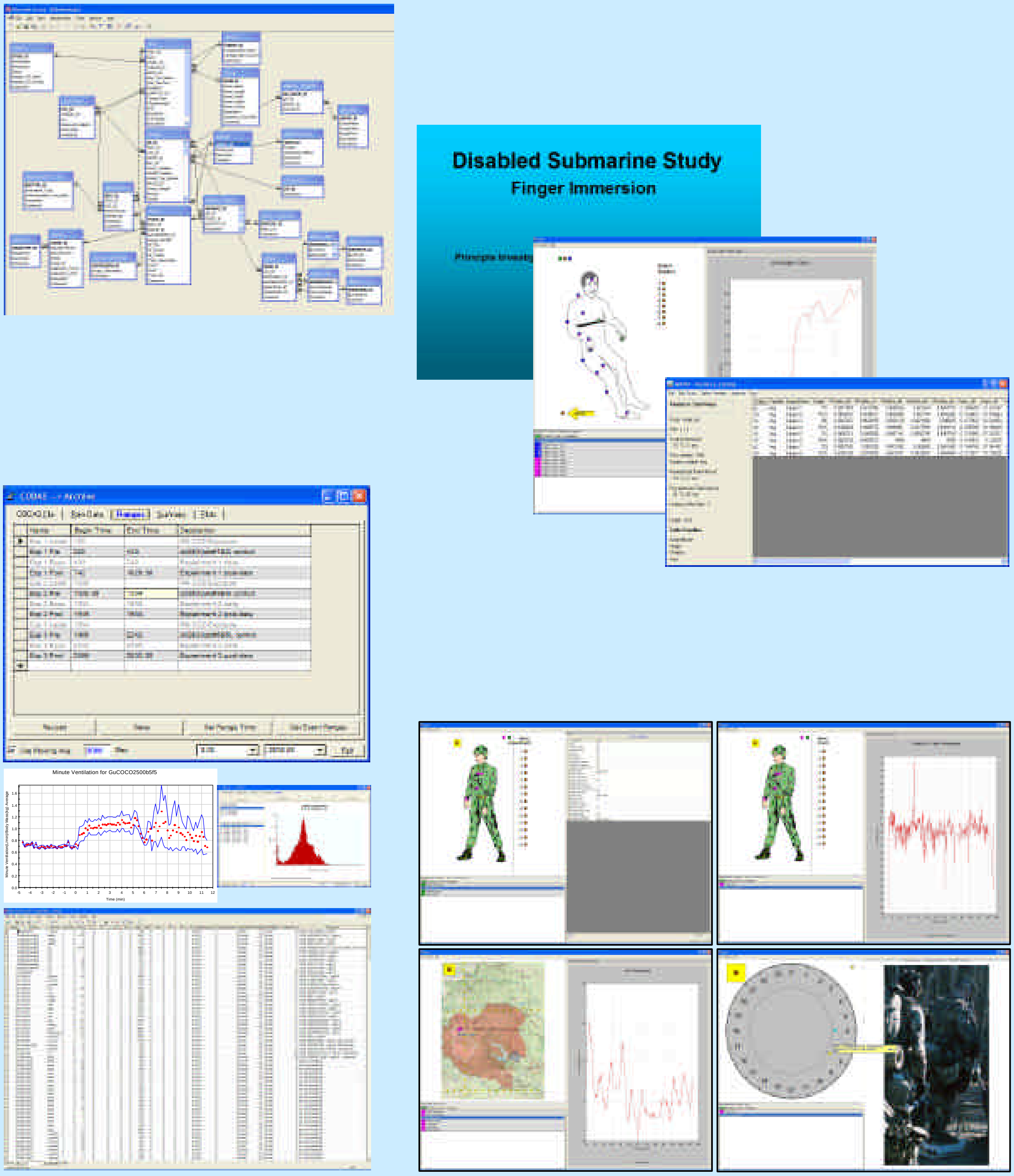


The Bulls Eye Tekscan Sensor for measuring impact pressure distribution time histories



Comparison of pressure measured from one cell of the Bulls Eye Sensor compared to that calculated from a force gauge

8. Data Preservation



BLAST DATA PRESERVATION

Significance

Blast injury continues to be a major concern to modern military personnel. Virtually all of the free world's animal testing on blast effects was conducted at the Blast Test Site in Albuquerque, NM from 1950-1995. Those data are preserved at L-3/Jaycor and are being systematically recovered for use in answering current questions.

Product

--Blast Overpressure Database, Ver. 1.0, Diane Long, 2005.

--Kirtland Literature Database, Berlinda Martinez and Brenda Tracy, 2006.

--BOP Data Inventory, Brenda Tracy, 2005.

Research on the biomedical, biological and bio-physical effects of blast and shock was conducted at Kirtland Air Force Base, New Mexico from the early 1950's through 1997 (Martinez 1999). The Blast Over-pressure Program obtained data that were essential to the understanding of the broad and complex nature of biological effects of blast overpressure and impulse noise.

The primary mission of the research effort was to support programs of national interest by conducting research into the biological effects of exposure to blast overpressures. The experiments performed were designed to address some important military and civilian issues. The results obtained played a major role in the development of blast safety standards, the treatment of blast injuries, development of weapon systems, and tactics to deal with blast overpressure.

L-3 Communications/Jaycor (Jaycor) acquired this data to develop an injury criteria program that will predict injury thresholds to the soldier under different blast conditions. Jaycor was also given the task of documenting the history of this major research effort on the biological effects of blast overpressure and impulse noise and to preserve and archive as many of the documents as possible. The first major task involved inventorying and identifying the materials received from Lovelace, then cataloging, digitizing and organizing the data. so it could be integrated into our current BOP project.

During this contract period Jaycor redigitized all BOP photos that were received previously for higher resolution files with JPG output. We also located and digitized newly found photos and slides and integrated them into the BOP system. Two new studies with behind armor data were identified under the current contract. These were complete studies with pathology sheets, traces, photographs, and logbook pages. All the data was digitized and entered in the database.

Another major effort during this contract period was the development and population of a newly design-ed database. A quality control was performed to verify that the proper pressure traces were being used by INJURY for each animal. The data was organized into a directory structure that allows INJURY to be run from the QC'd data in the database. A "read only" version of the database was then created and the data is a benchmark for running new correlations for the INJURY software program.

A Kirtland literature database has been created and all the reports have been digitized. The database has links to the PDF versions of the reports and papers and copies of those that are relevant to the different BOP studies have been put in the study folders.

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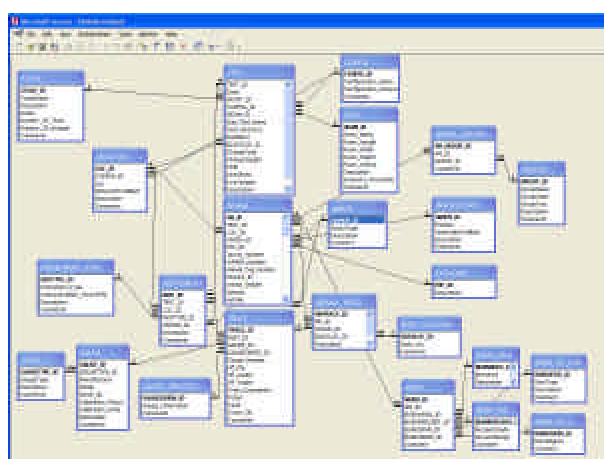


Structure and relationships of BOP database.

DISABLED SUBMARINE STUDY

Significance

The MOMRP sponsors a wide range of research projects that produce critical data for understanding physiological processes. In the normal course of conducting this research, data is usually only used by a single investigator and the data and the findings are not routinely archived. The rapid access to this wide range of data would make future research more efficient and eliminate potential duplication. This project demonstrated the capture and analysis of one such data set.

Product

--IISYS data session for the Finger Immersion portion of the USARIEM Disabled Submarine Study. Diane Long (2000).

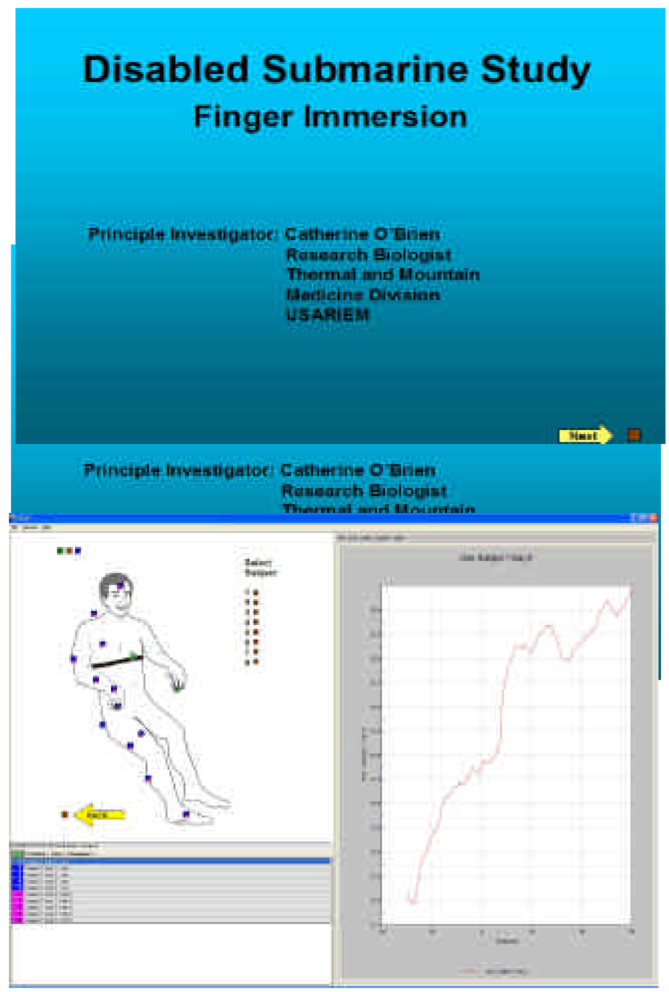
--ANOVA software version 2.2. Diane Long (2000).

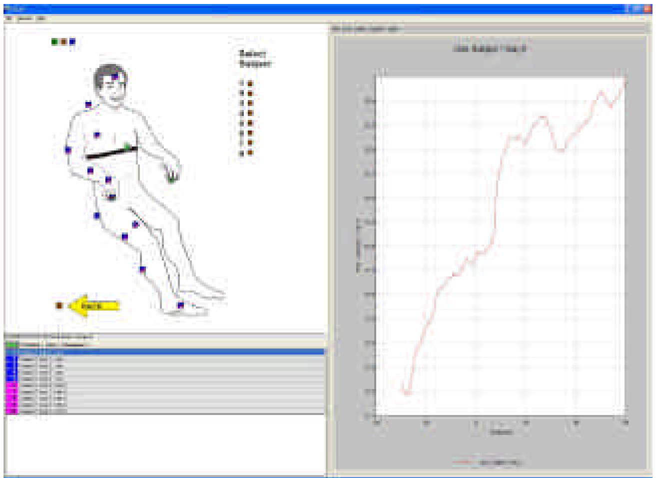
The Disabled Submarine Study investigated the effects of various environmental parameters on the response of the thermoregulatory system as measured by the response during finger immersion in cold water. The experiments measured the time variation of temperature, heat flux, and blood flow in as many as 10 body locations. These data were being stored in spreadsheets by the investigators.

Jaycor developed an IISYS data session for the available data. The data was translated into the General Data Interchange Format (GDIF) and stored in a hierarchical directory. The GDIF files are self-documenting with variable, units, and labels. Context figures were developed to explain the location and meaning of each data trace. A database was established to capture the experimental parameters of each test. All of the data was made available through the Integrated Information SYstem Software (IISYS), which was installed on the USARIEM workstations.

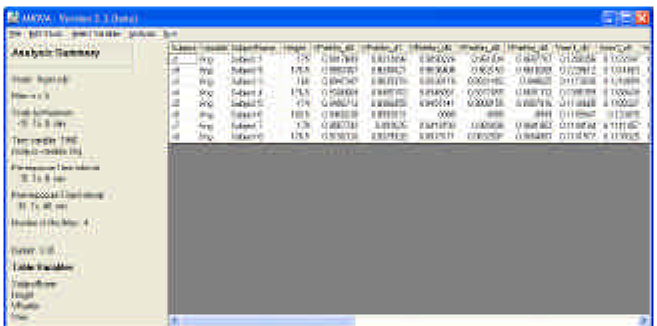
The analysis of the finger immersion data consists of identifying peaks and valleys in the temperature time history, determining the time between these features, and then conducting ANOVA statistical analyses to assess trends with test parameters. Jaycor developed a special software analysis program that worked directly with the data in the IISYS system to automate the entire analysis process. The automated software increased accuracy, provided an audit trail, and reduced the manual labor of analysis by many fold.

DISSUB IISYS Session





Finger Temperature Variation



ANOVA Program

ViewCODAS

Significance

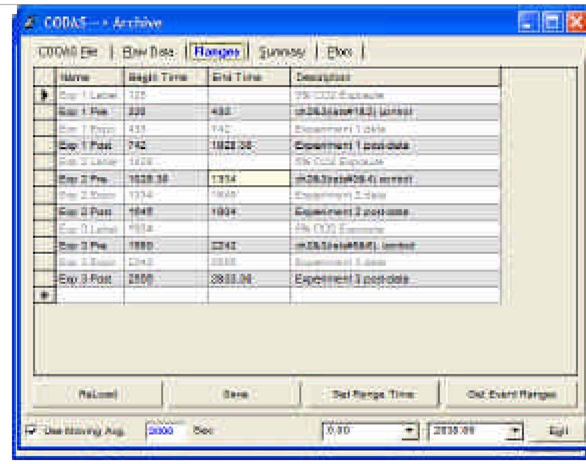
Hundreds of small animal ventilation experiments were conducted by WRAIR in support of the development of the TGAS software. Because of the exploratory nature of the work, the analysis of the data was more comprehensive than any other in the past. The data could determine subtle changes in the details of ventilation with each toxic gas exposure, as well as the standard, average ventilation parameters. In order to have a close, nearly real time coupling between the experiments in Washington DC and the mathematical analysis in San Diego, the ViewCODAS software was developed to automatically analyze data collected on WRAIR's data collection system and compute all of the relevant quantities. This work represents one of the most systematic cooperation of MOMRP research laboratories in a single project. The data has been used in developing several key mathematical models and insights into critical physiological processes.

Product

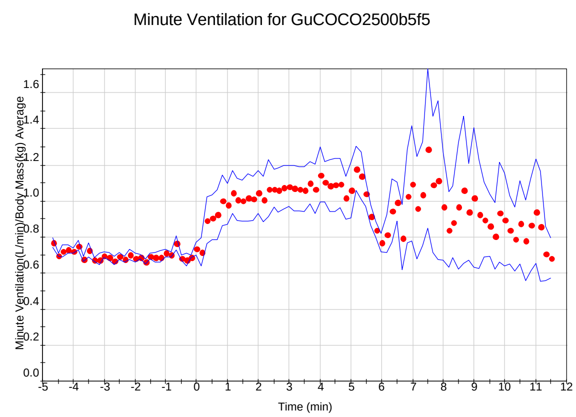
--ViewCODAS software. Warren Chilton (2000).

--Toxic gas experimental data base. Diane Long (2003).

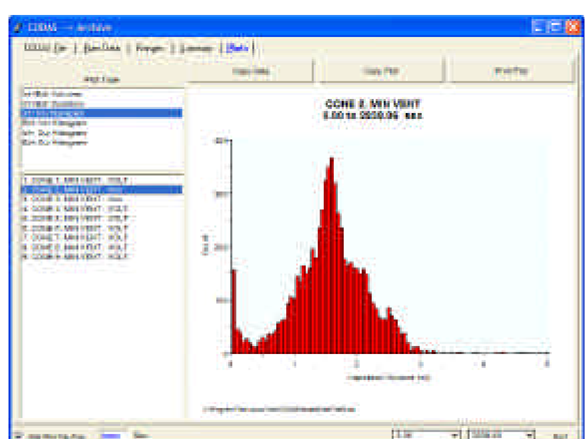
JAYCOR's ViewCODAS application provides a way to review and analyze rat respiration data collected and stored in the CODAS file format. By reading data directly out of the CODAS binary file, we are able to preserve the original data while providing a means of very quickly computing the summary values which are important for analyzing data of this type.



ViewCODAS Program

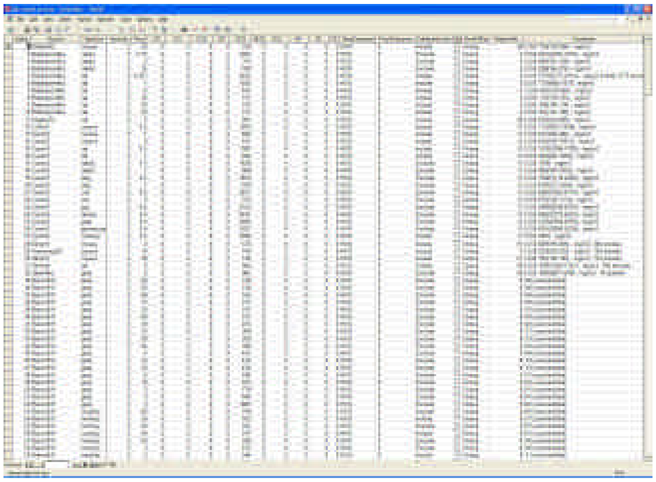


Small Animal Data



Inhalation Histogram

L3 communications



Data Table in Toxic Gas Database

WPSM Data Preservation

Significance

The Warfighter Physiological Status Monitor (WPSM) is an important, next generation application of the collective knowledge of physiology gathered by the MOMRP. The great promise of multiple sources of data is in the fusion of these data to allow inferences far more powerful than any single piece of data. To be able to find those patterns, it is critical to be able to rapidly analyze a wide collection of time history, photographic, relational and other data types. This effort placed field test data of the WPSM system into IISYS data sessions that provided that rapid analysis capability.

Product

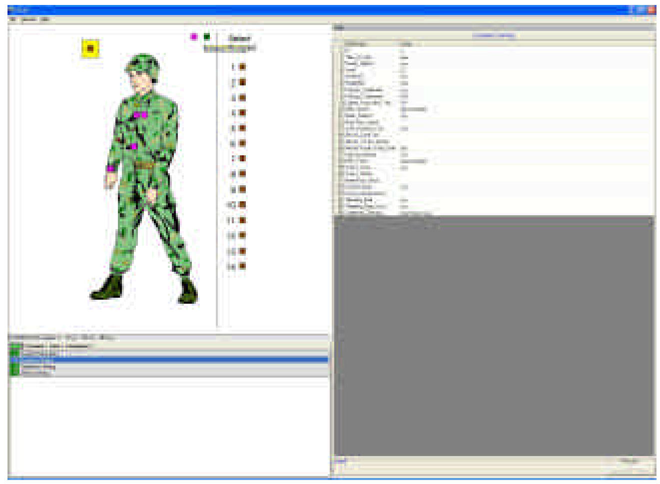
--Quantico IOC1 IISYS Session. Diane Long (2001).

Data, using the WPSM instrument ensemble, was collected at Quantico Marine Base over a period of several weeks. The raw data, in the form of time-traces, photographs, video, and relational data was processed by Jaycor into standard data formats. The time-history data was converted to General Data Interchange Format (GDIF), the video into AVI format, and the relational data placed into a specially designed MS Access database. The data from each subject were stored in a hierarchical directory structure. Context diagrams were developed to show the location of all data collected. Geographic data was translated to standard coordinates. Video was synchronized with time-history data, were appropriate, to demonstrate that physiological processes could be correlated with activity. Additional plug-in data viewers were developed to display and link unusual data types, such as calendar based schedules.

An IISYS session was developed that ran off the data structure. The IISYS software was installed on USARIEM workstations and the final product demonstrated for both management and researchers.

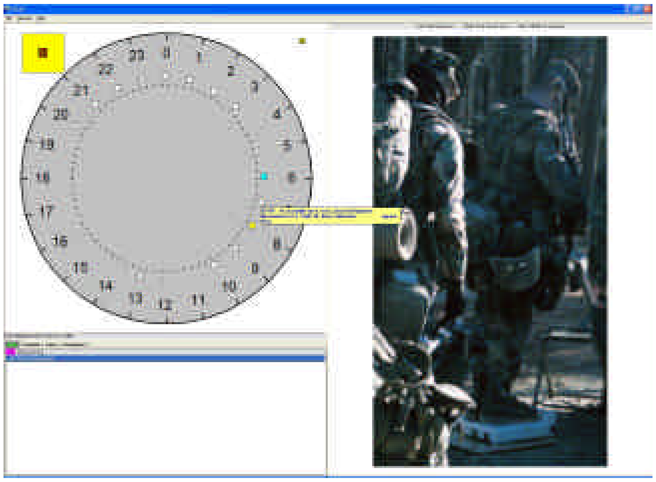
Templates were developed that would allow USARIEM researchers to enter data into the IISYS session in real time, in the field, and obtain immediate analysis of tests and comparison with previous field trials. Specialized IISYS viewers were developed to analyze data for specific quantities, such as the cold stress criterion.

This work showed that multiformat data can be stored and retrieved intuitively and that prospective studies can take advantage of the IISYS system to shorten the time to understand and adapt tests.

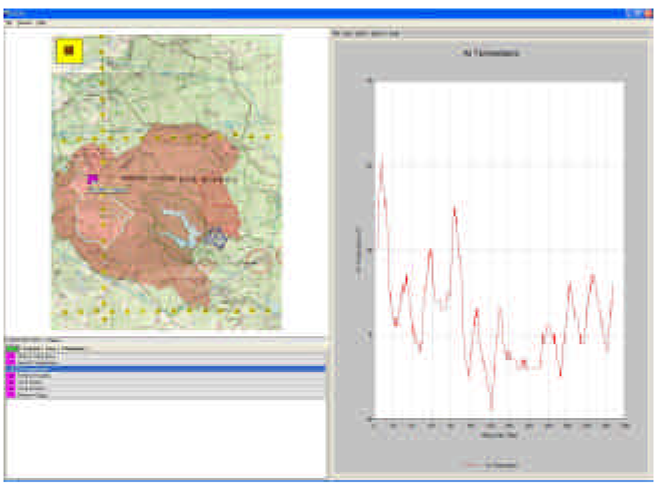


Subject data

Chest temperature



Video linked with schedule



Temperature correlated with movement

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